THESIS FOR THE DEGREE OF MASTER OF SCIENCE IN THE

UNIVERSITY OF LONDON

SPOROMORPHS FROM CERTAIN COAL SEAMS IN THE RUHUHU COALFIELDS OF TANGANYIKA

AUDREY NAYLOR

1959

ABSTRACT

During the course of the Colonial Development Corporation's investigation of the Ruhuhu Coalfields of Tanganyika, it became apparent that the full stratigraphical relationship of the economic seams was more complex than was anticipated. This was partly due to the drift origin of the coal, and its supposed accumulation in isolated lacustine basins, divided themselves by sandbars. Lack of macro-fossils during mapping and exploratory trenching was noticeable. Diamond drilling with 1¾" cones yielded only lithological relationships between seams.

It was therefore suggested by the author, that in the absence of palaeontological evidence in the intervening strata, a study of the microspore content of the coal seams should be undertaken, with a view to exploring the potentialities of this method of seam correlation within each coalfield.

Constant reference has been made to the researches of Permian spore workers in other continents, and of Carboniferous workers in Europe and U.S.A. This preliminary work on East African coals is, of necessity, observational. Techniques specific to these coals are described in detail, including sampling, preparation and presentation methods.

A new classificatory system of fossil microspores, designed for ease in identification of spore-morphs for stratigraphical use is presented. Linnaean nomenclature has not been adopted, nor is it advised until extensive comparative work has been done on these coals. Regard has been paid to existing classificatory schemes used by workers of both Carboniferous and Permian researches. A complete section is devoted to comparisons of the main classificatory schemes in use.

The stratigraphical work deals with the use of spore counts to give microfloral assemblages for full or part seams, and to give a sequence of floras. The cores of two boreholes are considered in detail, and the significance of the results is discussed.

INDEX

LIST OF FIGURES AND CHARTS IN TEXT

FIGURES 1-26

ACKNOWLEDGEMENTS

The author wishes to express thanks to the Colonial Development Corporation for permission to use samples and information belonging to the Corporation, and especially to Mr H.A.Cochran and Dr. T.Pickering for unfailing help given at all times.

To the University College of North Staffordshire, I owe thanks for the provision of facilities often at the inconvenience of both Chemistry and Geology departments, and to Professor F.W.Cope and my Colleagues for advice and help.

Thanks are also due to Professor L.R.Moore of the University of Sheffield for guidance throughout the work, and to the research staff at the M.C.B. Research Laboratories at Chester and Sheffield for advice at various stages.

I should also like to express my gratitude to Professor J.S.Westoll of King's College, Newcastle-upon-Tyne, for the critical advice and encouragement given during the difficult closing phases of the thesis.

The aim of the investigation was to discover whether microspores could be identified from the coal bearing rocks of the Ruhuhu Valley and used in the correlation of the coal seams.

The report has been divided into two major parts, the first dealing with the recovery, identification and description of the sporomorphs, and the second dealing with the techniques and results of a detailed seam correlation.

Introductory sections cover the background of the investigation in brief, and a survey of published work on Permian coal spores.

I N T R O D U C T I O N

INTRODUCTION

'Microspores' in Palaeontology and Stratigraphy

Since the early 1930's a great deal of interest has been shown by research workers, in the microfossil content of coals, although authors had reported the presence of minute plant fragments in coals at intervals throughout the preceding 100 years.

One of the probable reasons for the intensified study of microfossils from coal was, that for the first time, it was realised that the fossil content of the actual coal seams could be used as evidence for the correlation of the seams. The macro-fossils from the intervening strata were formerly the only reliable fossil evidence for the correlation of the coal measures ie. the mussel bands and the plant remains from the associated carbonaceous shales and sandstones.

The microfossils present in the coal are small fragments of plant tissue - vascular tissue and cuticle - and the numerous micro-, iso- and mega-spores produced by the original plants that made up the coal measure flora. Of these groups, spores are the most abundant, and in many cases the most resistant remains in the coal. Hence, it is the spores that have the greatest potential for study as a group of microfossils to be used in correlation.

The general term 'spore' can be used to cover all the varieties of minute organisms produced by a plant during its reproductive cycle. The term can include the mega-, iso- and micro-spores produced by the lower groups of plants as well as the pollen grains produced by the higher groups such as Pteridosperms and Gymnosperms. For the purposes of stratigraphy, these organisms can be treated as one fossil group, although in actual fact they are morphologically and functionally dissimilar. For descriptive purposes, many apparently similar forms are considered together, regardless of origin or function as there is no method of distinguishing between spores of different parentage, nor of establishing the relationship between the spores and their p parent plant. It also follows that, in fossil material, it is not possible to separate micro-, and iso-spores from small megaspores.

For systemmatic purposes in this study, the term 'Sporomorpha' is used. The term was suggested by Erdtman in 1947, to eliminate the necessity for distinguishing between botanically different types that appear morphologically similar, ie. a 'form genus'. To quote broadly, a sporomorph may be the product of several species of plant placed in one group, or of many products of diverse parentage grouped together through similarity of form. Alternatively, one species of plant may produce several sporomorphs. It can be seen that the term 'sporomorpha' can include all smallspores when the upper limiting size is placed at about 150/u diameter. The problems of classifying these sporomorphs will be discussed at a later stage, but it must be seen that there are distinct problems where such differing organisms as spores and pollen grains are considered under one heading.

Due to their resistance to decay, the outside skins, or exines of the spores, have remained almost unchanged since they were produced by the coal measure vegetation. In some cases the plant fragments may not have escaped the initial oxidation and decaying processes of the coalification, or have been destroyed by subsequent metamorphic changes in the coals. It follows that a normal rank coal will have some spores at least in it, whereas a high rank coal would tend to be devoid of spores. It is this inherent resistance to decay that makes it possible to extract and recover spores from coal by oxidation of the coal with acid and the dissolving away of the humic material with weak alkali.

The distribution of spores in the coal series is mainly due to aerial dissemination, much as pollens are distributed as 'rain' at the present time. Spores are produced in enormous numbers by a great variety of plants, many of which may be too fragile to be preserved themselves in the coals and associated sediments. The variety of spores actually preserved in the coals must therefore be much more representative of the population of the coal measure flora than the sparse fragments of plants which become fossilised. Plants such as the Bryophyta would have little chance of preservation althought the spores they produced would be resistant enough to be preserved. Therefore, the assemblage of spores from any one locality can include representatives from the lowest to the most highly organised type of plant present in that locality at any one time.

The relative abundance of any one type of spore at a certain horizon does not necessarily indicate the relative abundance of the parent plant, for it is known from the study of recent pollens that different species produce differing quantities of pollen. Hence a dominant plant type may be represented by a small number of spores, whereas a dominant spore type may have been produced by a less well represented species of plant. Thus, the analysis of a sediment for spore content, whether shale, coal or peat, can be qualitative only, not quantitative.

However, the absolute abundance of types does not affect the underlying principles of analysis of sediments for microfossil content, for the interpretation of the assemblage is based on the relative proportions of the various sporomorphs present at any one horizon to one another, or the proportions of several forms to the whole assemblage, not the actual numbers present.

With aerial dissemination of spores as 'rain' mixing of the species will take place before deposition, and the resultant composition of the rain will be fairly constant over a considerable area. Small local patches of a distinct plant may produce small local vatiations, but over an area of several square miles, the spore content will be more or less constant.- whether the sediment deposited is sandy, muddy or coaly. In this respect spores are not a facies fossil but a reasonably reliable horizon fossil. Instead of being deposited at their place of origin ie. under certain specific ecological conditions, the spores are deposited at a distance, not necessarily great, from the hinterland where the parent plant grew. A changing population of plant life in the hinterland would be reflected in a changing assemblage of spores in the sediments. This is especially true of coals laid down as plant débris in lacustrine conditions, as compared with those coals which grew in situ in a coal swamp, and were more likely to be affected by local variations in plant populations.

The Ruhuhu coals of Tanganyika, in all probability, were laid down under lacustrine conditions. They are dull coals containing a high proportion of finely disseminated mineral matter, although minute bands of brighter coals occur in some of the seams. Occasional partings of fusain are found but in general the coals are even textured. The intervening strata of sandstones, siltstones and shales have yielded little in the way of fossil remains. The outcrops are extremely weathered, and most of the exploratory work has been carried out by diamond drilling. The seams have a tendency to thin and thicken in short distances, as also do the intervening sandstones. Some seams may reach a thickness of 20 feet in one place, while the same seam is represented elsewhere by a mere 6-8 feet. Correlation is made difficult by this feature and by the fact that the coal sequence itself appears to differ in different parts of the same coal basin. A brief description of the geology of the coalfields will be given at a later stage.

It was to determine the value of microspores in the correlation of the coals seams under such conditions as in the Ruhuhu Valley of Tanganyika that it was decided to extract and study the sporomorphs (if present) of certain of the coal seams of these coalfields. Up to the time this study was c ommenced the only African Permian material to have been studied were a few pieces of Natal coal, which had been macerated for spores, producing a poor selection of forms bothin variety and quantity. However, the difference in locality and type of coal in the Ruhuhu fields warranted an experiment being made in the extraction of spores where no record of any type had been made.

This research project was suggested to me whilst working

On the Tanganyika Coalfields Investigation as an executive at the head office of the Colonial Development Corporation in London. The project was started in 1953, by permission of the Colonial Development Corporation, and was carried out during three and a half years as a demonstrator in geology at the University College of North Staffordshire, and completed during 6 months at King's College, Newcastle-upon-Tyne.

S E C T I O N   I

I N T R O D U C T O R Y   B A C K G R O U N D

SECTION I : INTRODUCTORY BACKGROUND

(1) Colonial Development Corporation's Tanganyika coalfields Investigation.

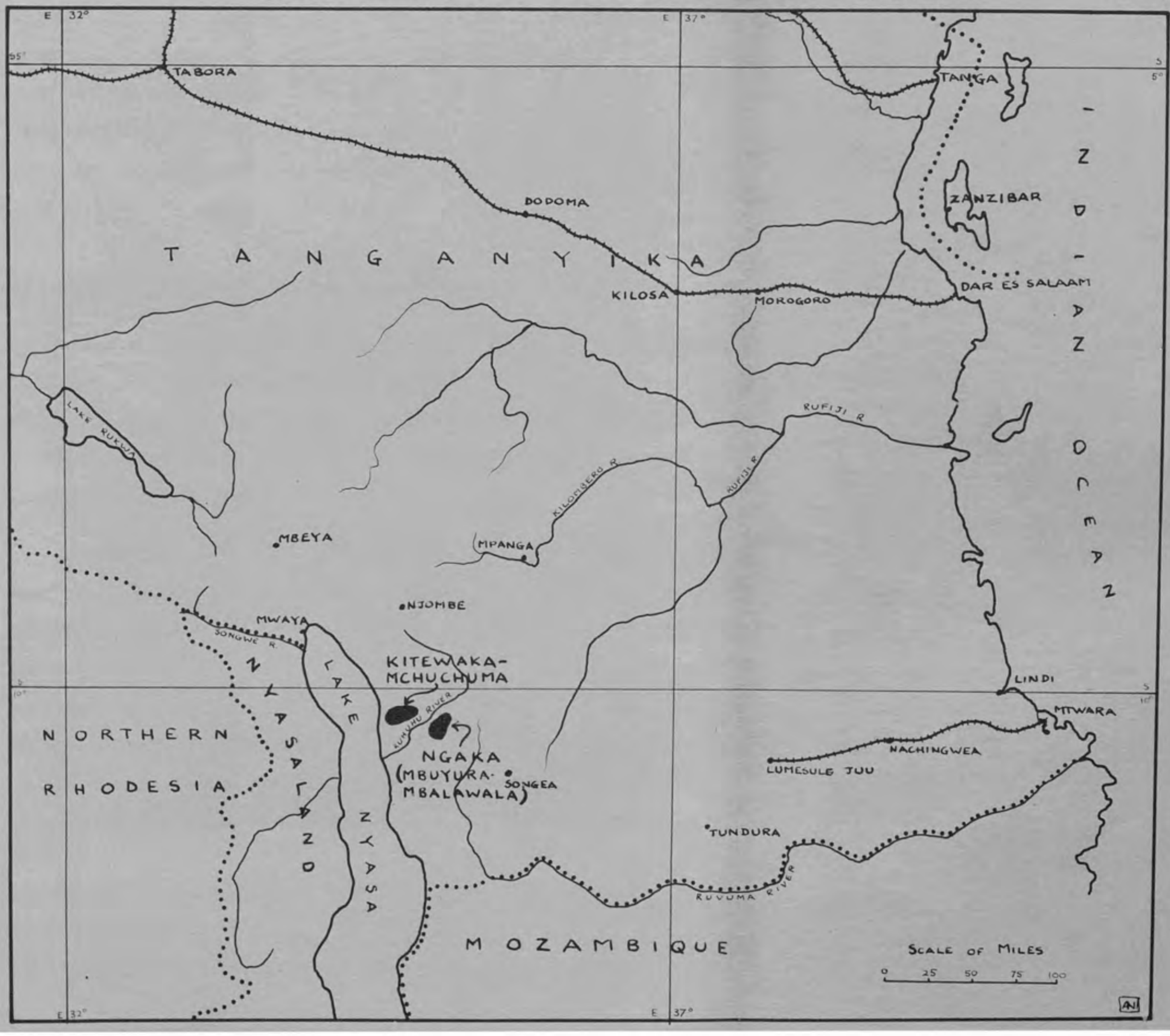
In 1949 the Colonial Development Corporation was asked to investigate the coal resources of the Territory by the Tanganyika Government.

As early as the end of the 19th Century, the German traveller and geologist BORNHARDT had noted the occurence of important coal bearing sediments in the Lake Nyasa area of the territory. The Ruhuhu area of Karoo sediments was investigated by G.M. STOCKLEY whose bulletin published in 1931 reported the presence of coal in the Ngake area, but only carbonaceous shales in the Mbalawala and Mchuchuma areas. Detailed mapping was carried out by A.C.M. McKINLEY during 1948/49 and published as a bulletin in 1954. It was this latter author who was responsible for the detailed stratigraphic work which lead to the now recognised zoning of the coals. This involved the division of the Coal Series into two major parts - the Coal Sandstone Series below, containing good, clean economic seams, and the Coal Shale Series above containing less valuable seams.

However, it was the Colonial Development Corpoation's team of field workers who eventually revealed the immense resources of economic coals in this remote area. The in-

LOCATION MAP OF RUHUHU COALFIELDS

FIG. 1.



vestigation took place between 1949 and 1953 during which time four distinct coal basins were recognised and three of them extensively mapped and drilled. The Mbuyura or North Ngaka and Mbalawala fields comprise the Ngaka Area to the east, and the Mchuchuma and Kitewaka fields are to the west. (fig 1)

(2) General Geology of the Ruhuhu Coalfields.

T The coalfields are situated in the Songea-Njombe District of the South west Province of Tanganyika. There are two distinct valleys - those of the Ngaka and Mchuchuma Rivers to the east and west respectively - covering a total area of about 160 square miles.

In general, the succession in both areas consists of a varying thickness of cushioning sediments laid down on the irregular Basement Complex, and overlain by the Coal Series. The latter consist of a lower series of clean coals in sandy sediments - the Coal Sandstone Series - followed by an upper series of carbonaceous shales and sandstones with seams of variable thickness - the Coal Shale Series. In turn these are overlain by a series of red beds and sandstones laid down at the close of the period. In age the sediments represent the middle of the Ecca Series of South Africa. It is suggested by various authors that the warmer conditions after the Gondwana glaciation, spread from the south thus accounting for the apparent lack of earlier Dwyka rocks in the more northerly Karoo sequences of Central and East Africa. The coals are thus, of undoubted Permian age.

The four coal basins already mentioned, are dissimilar from both the geological an d mining points of view, having been laid downin separated basins, not just isolated into basins by later erosion. Two coalfield types can be recognised, namely (i) the Mbalawala Coalfield type, characterised by clean and persistant seams in a sandstone sequence. and((ii) the Northern Ngaka Coalfield type, characterised by local small basins with impersistent seams 'hugging' the pre-Karoo floor, with only a thin cushion of sediments between them and the irregularities of the Basement configuration.

The pre-Karoo landscape in which these sediments were laid down, is visualised as a large irregular basin, having undulations of the surface resulting in local 'highs' and 'lows' which represent the original spurs and valleys. The Karoo rocks filled up the local depressions, gradually enlarging the continuous area of deposition, until by upper Karoo times the whole area was one large basin. The whole of the Ruhuhu area can be visualised as a 'multi-basin', in which a coalfield like the Mbuyura field consists of a series of'micro-basins'. The latter shows only moderate relief in its Basement features, whereas the Mbalawala field has one major depression which shows a drop in the Basement floor of some 2,000 feet in a little over a mile.

It was on to these variable Basement features that the coal measures were deposited, and consequently a great depth of sediment can be traced in one microbasin, whilst in another only a mile or so away shows a much thinner series of rocks due to a higher Basement level.

The Coal Sandstone Series (K_2e_1) was deposited in the embayments and small valleys in the Mbalawala and Mchuchuma coalfields. It is comparable with the Wankie coal measures of Southern Rhodesia, and consists of sandstones with associated clean coals. When the depositonal basin remained stable, coals of a considerable thickness were laid down, being relatively clean over a total thickness of as much as 20 feet in some places in the Mchuchuma field. Minor basins were formed by the presence of sand bars within the area of coal formation. The deeper embayments permitted the deposition of a thick sequence of the basal Karoo rocks which, although not continuous over the whole of the Basement floor, at least smoothed out the minor undulations thus enablingthe accumulation of a continuous coal band over a more restricted area. The coals of this series are the most important from an economic standpoint.

The Coal Shale Series (K_2e_2) were deposited under less stable conditions than the previous series. The environment was predominantly muddy with shifting coal basins. The coal seams formed at this time are, on the whole, rather dirty grading laterally into shales and mudstones. Many thin coals with interbedded carbonaceous shales resulted, and the coal seams proper form only a small percentage of the sequence. By the close of the period, the more sandy conditions prevailed once more but no further coal bands were deposited, The subsequent strata are of the arid red bed type of the Upper Karoo.

The Mbuyura coalfield with its micro-basins, has only a thin covering of sediments of the earlier Karoo type between the coals and the basement beds. This is reflected in the nature of the coals, for the underlying surfaces have influenced the deposition to such an extent that the coal seams conform to the general basement features, resulting in the lensing of the seams. Local areas of contemporaneous erosion have given rise to further inconsistencies.

The coals themselves occur in the form of occasional thin laminae of vitrain and fusain set in a matrixof dull, blocky coal. The durain comprises the bulk of the economic seams. Seat earths are non-existant, and plant remains rare. The evidence points to a drift origin for the coal, as can be seen in the high ash content and the finely disseminated nature of the coal material. A lacustrine environment is suggestedfrom the evidence of sandbanks and other features.

The field investigation was from an economic aspect ~~only~~, hence interest was taken in seams of workable quality and thickness only - here taken as 3 ft. 6 ins. with a 3 ft. seam occasionally taken into account. The limiting specific gravity was taken with its maximum at 1.5 and / or an ash content of less than 25% by proximate analysis. The micro-spore work was confined to the consideration of seams within these set limits for economic seams as defined above.

In the Mbalawala Coalfield four possible economic seams were recognised namely, in descending order stratigraphically;

Coal Shale Seam

Upper Split Seam

Lower Split Seam

Bottom Seam

The Mchuchuma Coalfield has seven relatively persistant seams in the Coal Sandstone Series of which three are economic and two minor ones are economic in restricted areas:

'Coking Seam'(thin but having caking properties)

Top Economic Seam

Intermediate Seam (of restricted occurrence)

Middle Economic Seam)
) Thick Seam
Lower Economic Seam)

The sequence of seams in the Mbuyura field is not continuous so that the coals cannot be ranked as economic. The Kitewaka Coalfield was not investigated in detail but is considered to be the eastern extension of the Mchuchuma coal basin.

Both proximate and ultimate analyses were carried out on all economic seams, and wieghted average analyses calculated for the workable portions of each seam from the results of the analyses from the borehole core samples. These are summarised on page 14a.

(3) Brief survey of Permian Coal Measures of the Southern Hemisphere.

(a) East and Central Africa

(i) Tanganyika

Besides the Ruhuhu valley, discussed in the previous paragraphs, coal bearing Karoo rocks of similar age are to be found in several small coalfields in Tanganyika. The more more extensive ones are the Kivira Songwe field (now also investigated by the Colonial Development Corporation) and at Manda, in the Rukwa area.

(ii) Kenya

Permian coals are known to occur in the coastal belt

Proximate Analyses of Ruhuhu Coals (wieghted average)

		s.g.	moist	V.M.	F.C.	ash	Calorific val. BTU/lb
Mchuchuma:	Top seam	1.47	1.6	22.7	57.3	19.7	12,040
	Middle	1.40	1.7	24.0	60.3	14.0	13,040
	Lower	1.39	1.6	22.7	62.4	11.5	13,430
	Thick	1.42	1.5	23.4	61.3	13.8	12,950
Mbalawala:	Coal shale	1.47	3.2	25.0	53.7	18.1	11,790
	Upper split	1.43	3.4	25.2	55.8	15.6	11,840
	Lower Split	1.38	3.5	27.2	57.3	12.0	12,800
	Bottom	1.37	2.7	30.7	53.2	13.4	13,020
Mbuyura average:		1.43	2.3	24.4	56.9	16.4	- - -

Ultimate Analysis of Ruhuhu Coals (weighted average)

		ash	C	H	N	S	O plus errors
Mchuchuma:	Top Seam	18.2	70.2	3.7	1.7	0.98	5.2
	Middle	12.9	75.3	4.1	1.8	1.1	4.8
	Lower	11.5	77.2	4.2	1.9	0.6	4.6
	Thick	13.5	74.9	4.0	1.9	0.7	5.0
Mbalawala:	Coal Shale	18.0	68.8	3.9	1.8	0.9	6.6
	Upper Split	17.2	69.0	4.0	1.7	1.1	7.0
	Lower Split	12.3	74.1	4.3	1.7	0.7	6.9
	Bottom	13.7	71.8	4.6	1.7	2.0	6.2

Mbuyura averages not available.

but so far have not warranted investigation.

(iii) Nyasaland

The Ecca coal bearing series is represented by the Mwanza Shale, a Lower sandstone and a Shale group, of which the latter of Upper Ecca age, is the coal sequence. This consists of about 3,000 feet of sediments, divisible into two shale groups separated by a sandstone series, containing mudstones, carbonaceous shales and coals. In the south of Nyasaland are the Chiromo and Sumbu coalfields, bothof which are small and uneconomic. Centrally is the Livingstonia coalfield in the Mount Waller district. In the north the Nkana coalfield, situated in the Songwe River valley, is the continuation into Nyasaland of the Kivira-Songwe field of Tanganyika. These two latter fields may be worked eventually but little has been done on them as yet,

(iv) Northern Rhodesia

The coal series of Northern Rhodesia is probably of Upper Ecca age. It consists of clays with coals, six to eight feet thick, in a series of sediments 3-400 feet thick. A flora of Glossopteris, Gangamopteris and Schizoneura has been recorded. Coal bearing rocks are known to occur in the Kafue and Zambesi River valleys in the Southern Province and in the remote Luangwa valley of the East and Central Provinces.

(v) Southern Rhodesia.

Karoo rocks extend from the Zambesi River area to the Bulawayo district. The Ecca Series shows the typical three-fold division of the South African sequence, although both the Lower and Upper divisions are of Wankie sandstone, typical of that coalfield. The Middle Ecca consists of shales, coals and fireclays, particularly well developed in the Wankie Coalfield, which is the Territory's large producing field having several thick seams of good quality coals. A flora including Glossopteris indica, and Cardiocarpus sp. is reported.

(vi) Portuguese East Africa.

Coal is again present in the Zambesi River area, in the middle and lower regions. The Karooorocks of this area are probably not earlier than the Ecca Series. The lowest group consists of current bedded sandstones and shales containing ironstones and coals. These are widespread in the Muatize and Tete areas. Glossopteris spp. and Schizoneura sp. have been collected from the shales.

(b) Southern Africa

(i) Bechuanaland

The Ecca Series as found in Bechuanaland is a continuation of the Waterburg Coalfield of the Transvaal. Lower

Ecca shales are represented by 150-200 feet of dark shales. The Middle Ecca consists of sandstones, grits and shales with coals deceloped in places. Coal bearing Ecca beds are known to exist in the south east of the Protectorate, in the Palapye area (east central) and in the north as an extension of the Wankie coal area of Southern Rhodesia. Where Ecca beds have been investigated a typical Glossopteris flora has been found.

(ii) Swaziland.

Half the country is of Karoo sediments, and coal-bearing rocks of Ecca age have been found by mining investigation but have not been exploited.

(iii) Basutoland

The coal series is probably present under a thick cover of later material. It is believed to be the extension of the Cape Province Mining area.

(iv) South Africa.

In South Africa the Karoo System has been divided into four Series, of which the Ecca is the chief coal bearing series. The type areas for each of thes series occurs in Soth Africa where their development is at its greatest. The basal beds are the Dwyka Tillites, the glacial boulder beds which have their counterparts in both India and Australia at the base of the Permo-Triassic sediments of those areas but are not necessarily of the same age.

Stormberg Series	Upper Gondwana, or
Beaufort Series	U. Permian to Trias
Ecca Series	Lower Gondwana, or
Dwyka Series	U. Carb. to L. Permian

The two lower series of beds correspond roughly to the Carboniferous and Lower Permian rocks of the Northern Hemisphere, while the Upper Permian and Triassic are represented by the two upper series. The latter beds are mainly of the typical red bed type of the Upper Karoo, and are extensive in Cape Province and the Transvaal. Although the Ecca Series is the main coal bearing series of Africa, in some areas of the south western area it is non-coal bearing and consists of 2-6,000 feet of shales and sandstones.

(a) North East. Transvaal and Natal

Lower Ecca beds here consist of about 14,000feet of unfossiliferous flags and dark shales. Middle Ecca beds or Coal Measures are mainly of sandstones with several shale bands and coal seams. The coals are assumed to have been formed in situ although no seat earths are found. Seams may occur up to 20 feet in thickness, having sandstone below and passing into shaley coals above. The whole series varies in thickness from 300 feet in southern Natal to a maximum of 17,000 feet at Mpofana in central Natal. Upper Ecca beds are of several hundreds of feet of flags and shales.

(b) Central Transvaal

The Ecca beds are represented here by up to 200 feet of Lower Ecca shales, a similar thickness of coal bearing strata, and about 300 feet of Upper Ecca shales. Fossils are rare, but Glossopteris spp. have been found in the coal measures.

(c) North West Transvaal

In thIn the Waterberg coalfield only about 100 feet of Lower Ecca shales are present, overlain by the main coal series of Middle Ecca age. A Glossopteris flora has been found in the Upper Ecca shales which are about 350 feet in thickness and contain some coals.

(c) India

The general sequence as given by Fox for the Permian sediments of India is as follows:

Panchet Series - Trias

Damuda	Raniganj	Kamthi	U. Perm.
		Raniganj or U. coal Measures	
	Barren measures	Mahuda	
		Kulti or ironstone shales	
	Barakar	Barakar of Lower coal measures	Lower Perm.
		Karharbari	
		Umaria Marine Beds	

Talchir Series - Upper Carboniferous

The Talchir Series are the glacial beds at the base of the Gondwana sediments, followed by shales and fine sandstones. In the Karharbari Coalfield of Bengal, coal seams occur in the upper beds of the Talchir Series and contain a flora of Glossopteris and Gangamopteris, but these beds may actually be of Damuda age.

The Damuda Series is divided into three stages, comprising a total thickness of sediments of about 8,500 feet. The Barakar Stage shows its best development as the Lower Coal Series in the Tharia Coalfield of Bengal, where it attains a thickness of about 2,000 feet and contains coals in shales and coarse sandstones. The coals appear to be of a drifted sedimentary origin for the seams may pass laterally into shales, or split repeatedly. The flora is of the Glossopteris type. The Rewa Coalfield of Bengal is also of this age. The ironstone shale Stage is barren carbonaceous shales, between the Upper and Lower Coal Measures. The Raniganj Stage of 5,000 feet of strata is the main division of the Damuda Series. It is mainly of sandstones with some shales and numerous coal seams as in the Raniganj Coalfield where a Glossopteris flora has been recorded.

Practically the whole of the outcrop area of these Series is limited to Bengal and the Central States such as Rewa. Permian rocks occur in the mountainous regions of the Punjab and the Himalya but are non- coal bearing.

(d) Australia

The general sequence of strata is as follows:-

		New South Wales etc.	Queensland
KAMILAROI	Upper Coal Measures	Newcastle Coal Measures	Upper Bowen
		Dempsey Beds	
		Tomago Coal Measures	
	Upper Marine Series		Middle Bowen
	Lower Coal Measures	Greta Coal Measures	Collinsville Coal Measures

Lower Carboniferous (or L. and M. Carboniferous.)

(i) New South Wales

The Greta Coal Measures vary between 150 and 250 feet in thickness in theHunter River District and 400 feet in the New England Range. The sequence is mainly of sandstones and shales, occasional oil-shales, and igneous rocks in the northern areas. A combined Glossopteris-Gangamopteris flora is present.

The Tomago or Middle Coal Measures ars separated from the Greta Measures by 6,000 feet of barren strata. The Measures are 500 to 2,000 feet thick in the Hunter River District and thinner to the south and west. Several coal seams are present with a Glossopteris flora.

The Newcatle or Upper Coal Measures are the chief economic measures of New South Wales. Below them are 2,000 feet of carbonaceous shales having no workable seams. The series is 1,200 feet thick, numerous coalseams being present separated by sandstones shales and conglomerates. *Glossopteris* and *Gangamopteris* are both present, the flora being similar to that of the Damuda Series of India.

(ii) Queensland

At the end of the Carboniferous era, there was a general sequence of marine sediments in the Queensland area followed by the Permo-carboniferous Coal Series. A similar sequence of coals is found to those of New South Wales. The Collinsville Coal Measures consist of sandstones shales and some coal seams. Brachiopods are present in the sandstones while *Glossopteris* is commonly found in the plant beds. The Upper Bowen Series comprises the main economic coal series of Queensland with sandstones and shales having inter-bedded volcanic rocks, and coal seams together with the marine strata.

(iii) Western Australia

The Permo-Carboniferous here consists of a Lower Marine Series and an Upper Series containing coals. The Lower Marine Series is thought to be the equivalent of the Productus Limestone of the Salt Range of the Punjab. Two coal seams occur at the top of the series. The Upper series are the productive measures of the Collie River district and the Irwin River area. The measures are mainly sandstones with some coal seams.

(iv) Victoria

The Permo-Carboniferous is represented in Victoria by the Bacchus Marsh Beds which consist of glacial tillites interstratified with shales, sandstones and conglomerates. No coals are found but the highest beds contain several species of <u>Gangamopteris</u>.

(v) Tasmania

Here the Permo-Carboniferous is represented by marine strata corresponding to the Bacchus Marsh Beds of Victoria. The Upper Marine Beds correspond to the Upper Marine Series of New South Wales. Between the two are the Lower or Mersey Coal Measures, the counterpart of the Greta Coal Measures of New South Wales. These beds are the Tasmanite Beds, of finely laminated shales and flags, interbedded with a a spore rich bituminous coal of a yellow colour - the true Tasmanite - believed to be of marine origin. The Mersey Coal Measures contain both <u>Glossopteris</u> and <u>Gangamopteris</u>.

(4) Review of Literature on Permian Coal Spore Work and other relevant work

The first reference to fossil bisaccate sporomorphs in sediments of Palaeozoic age in the southern hemisphere was made by SEWARD in the report of the British Antarctic (Terra Nova) Expedition in 1914. The so called pollen grain was a chance find in a section of wood from a boulder from Terra Nova (in Rhexoxylon Preistleyi) Previously, no record of Coniferous pollen had been made from rocks older than Jurassic. This boulder was believed to be not later than Rhaetic or Triassic. The explanation given for the presence of abietinous pollen in the Antarstic at sucha n early period was that it was possible that the conifers had evolved separately and independantly in the Northern and Southern Hemispheres. The report includes a general survey of the Glossopteris and Gangamopteris floras of both hemispheres.

Many controversial discussions arose from the discovery and description of the pollen grain Pityosporites antarcticus in the report of 1914, and a paper by SEWARD in 1932 defended the validity of the find. He maintained that the spore was n not a freak find, but closely resembled the pollen grain of the modern genus Pinus and other of the Abietinae.

Since the finding of Pityosporites antarcticus ther has always been a tendency in Permian spore work to look for more bi-winged microspores in these sediments, and to record this genus as far back in time as possible. Its presence in Permian sediments has been proved from India, Australia and South Africa, and in this present work, from East African coals. Earlier workers have over emphasised its importance for it is generally found in sediments of the Southern Hemisphere where a Glossopteris-Gangamopteris flora is present although its undoubted relationship to those genera has not been proved.

It was from these early beginnings in the recording of winged spores from the Permian sediments that it became apparent that the Permo-Carboniferous rocks of the Southern Hemisphere, especially the carbonacous shales and coals, would yield abundant microspores and other plant fragments on maceration.

C. VIRKKI, an Indian botanist, in 1937 published an account of an investigation of certain Lower Gondwana rocks of India and Australia and showed them to contain winged microspores similar to those of the genus Pityosporites antarcticus Seward. Plant beds from the Salt Range, Punjab containing Glossopteris and Gangamopteris yielded spores in association with cuticle from carbonaceous shales.

A Permo-Carboniferous shale from Newcastle, New South Wales, yielded two different types of Pityosporites, one considerably larger than the other. Again these spores were found in association with fronds and cuticle of a species of Glossopteris - G. browniana Brogniart. These discoveries extended the age range of Pityosporites spp. back into sediments of undoubted Palaeozoic age. Circumstantial evidence favoured the assumption that Pityosporites was the pollen grain of Glossopteris.

In 1939 VIRKKI reported on further spore types from sediments of Gondwana age from Australia and India. A sample of Dwyka Tillite from South Africa gave a negative result. The glacial tillite from Bacchus Marsh, Australia, yielded five spore types and a few tracheids. From the Salt Range of the Punjab, India, material above the boulder bed, shales from the same locality, shales from the Daltongunj coalfield and also from the Rewa Gondwana basin all yielded similar spore types. The forms recorded are 'monowinged' and the conclusion drawn by the author is that the Glossopteris flora existed as early as the Gondwana glaciation, at least in India and Australia.

In 1944 MEHTA inspected macerated carbonaceous shales from the Pali beds of the South Rewa area for their microfossil content. The shales, having a rich microflora, were macerated with hydrofluoric acid and Schultz soluion to release the remains. He recorded the presence of a one winged spore form - Hymenozonotriletes of Naumova - and a bi-winged form similar to Pityosporites? although possessing a thin bladder over the poles. The paper mentions the possible development of coniferous pollen from an ancestral form such as this latter.

It was VIRKKI in 1945 who produced the first comprehensive account and description of the spores from the sediments of the Gondwana System of India, and Australia. The samples taken cover five localities in India and two in Australia. The former were collected at intervals above the Talchir boulder bed, with two higher samples in the same series. The Australian samples were again from the glacial tillite of the Bacchus Marsh area and a Permo-Carboniferous shale from Newcastle, New South Wales.

The value of this paper lies in the detailed description of the spore found andthe classificatory methods used. A schematic classification is put forward, the spore genera and species being denoted by a numerical system. Emphasis is placed on thepresence or absence of wings, andtheir abundance detailed desriptions being given. A discussion is included on the possible development of bisaccate forms from a monosaccate form, the supposed intermediate forms being figured from actual specimens. The interest of the author appears to lie in the tracing of the Glossopteris flora as far back as the Gondwana glaciation at least, together with the recording of the associated Pityosporites type pollen.

The GHOSH and SEN 1948 paper (published two years after the completion of their work) was produced soon after Virkki's paper. It covers the plant microspore content of the Raniganj coals. These are from the representative beds of the Upper Permian of India. Over 50 spore types are described and placed in a numerical classificatory system, different from that of Virkki, and these types are then used to give microfloral assemblages for some of the productive coal seams in the Raniganj Coalfield. The stratigraphic value of the microspores is recognised as a promising field of investigation for coal seam correlation. Practical application of this is made in an attempt at identifying seams on either side of a major fault within the coalfield, by means of their microspore content. Emphasis is laid on the presence of Pityosporites type spores and a 'Pityosporites' microflora. Some types are compared with the Northern Province spores as found in Great Britain. Cuticle and fragments of wood were also extracted and described.

This was the latest of three independant attempts at providing a suitable classificatory scheme for Permian sporomorphs, completed within a year of each other, but not actually published within that time. The other two were that of VIRKKI in 1945 (India) and that of DULHUNTY in 1945 (Australia). The GHOSH and SEN classification was completed in 1946 (India).

It is unfortunate that three workers should have carried out this same piece of research simultaneously, producing three answers to the same problem without any apparent connection. It is not until a paper published in 1953 (SEN 1953) that any mention is made of Dulhunty's work in the Indian literature. Nor are the Indian classifications mentioned in Australian literature until 1954 (BALME and HENELLY 1954) when reference is made to both VIRKKI 1945 and GHOSHand SEN 1948. It appears that each area has followed the trend of its first worker, including the two separate areas in India, and hence the three parallel classificatory systems have been kept in use, as well as those operating in the study of spores in the Northern Hemisphere.

PANT, in 1954, showed further interest in the relationship between bisaccate sporomorphs of the Pityosporites type and Glossopteris - and in this paper, shows that these spores existed in Gondwana sediments as early as the end of the Permian glaciation. No definite proof can be given of the idea that Pityosporites is the pollen of Glossopteris although this conclusion is inferred.

In 1951, GOSWANI recorded the occurrence of microfossil remains in a single seam of coal from the Lower Gondwana Series of Rewa (Bandha Nala) India. The samples were poor in variety yeilding only one type of microspore - of the

Pityosporites type - although wood and cuticle were present.

In 1952, GOSWANI reported the occurrence of a variety of spores from a coal seam at Dharpuri (Bihar). The seam was mainly durain and yielded only winged spores - both the bisaccate (Pityosporites sp.) and monosaccate (Endosporites and Florinites spp.) being present, thus suggesting a coniferous type of vegetation.

SEN in 1953, published an account of 'Principles and Problems of Microfloral Correlation' mainly with reference to one Indian coalfield - the Karhabari - but concerned with a brief review of Indian work to date and the bearing that American, Australian and Russian research had upon the methods and the results. Although recognising the existance of other classifications for Permian sporomorphs, the author retains without revision the one previously put forward by him in 1948, and adds descriptions of several new types. The paper is primarily concerned with the use of microspores in the correlation of coal seams.

In 1954 PANT published a suggested classification of of spores and pollen grains, which combined the descriptive nomenclature of such workers as Naumova, Potonie, Ibrahim, Schopf, Wilson and Bentall and Coe among others. Included in this paper is a brief review of the classifications used in the period from Raistrick's numerical system of 1933 to the general classification put forward by Erdtman in 1947. Reference is made to earlier names but the emphasis is laid on providing a comprehensive classification, covering spores and pollen grains, with descriptive nomenclature. Only the actual scheme is laid down and as no descriptions are given many 'nomina nuda' are created. Many of these spore types have been described by later workers under different names, which are acceptable on the basis that this is not a valid classification. Synonymy with the Permian numerical systems is not given,- presumably it is left to their authors to fit the spores in where relevant.

DULHUNTY 1945 was the first reporter of microspores from the economic Permian coals of Australia, although it would appear that several other workers had commenced in the same field at about the same time. This first paper is a description of the methods and techniques employed in the isolation of the spores, and the detailed description of some 47 types according to a schematic classification based upon visible morphology and devised by the author for use in this piece of work. At such an early stage, no attempt was made to relate these types to those of the European and American Carboniferous coals, nor was it possible to compare with Indian material which was being investigated simultaneously, and was then still unpublished. It is stated to be a preliminary survey carried out on various coal horizons in the Kamilaroi coal measures of New South Wales.

A further paper by DULHUNTY in 1946 dealt with the s stratigraphical distribution of the spores previously described, within the coal measures of New South Wales, and their palaeogeographical significance. The microfloral assemblages are essentially of simple forms, relatively abundant in all seams studied, with monowinged and biwinged forms relatively less abundant. Samples had been obtained from the Upper Coal Measures (Newcastle and Tomago stages) and Lower Coal Measures (Greta stage). Evidence was collected to show that certain types have a restricted time range and might prove useful as index forms for correlation. No reliance is placed on correlation of the coals over any great distance on the basis that local vegetational changes would affect the microfloral assemblages.

In 1946 deJERSEY extended the recording of Permian spores in Australia to the Queensland coals. Separation techniques are described and the classification of spores devised by Dulhunty is used. The aspect dealt with in the paper is the description of new types not recorded from the New South Wales coalfields, the redescription of some of Dulhunty's forms in the Queensland coals, and the comparison with similar horizons in New South Wales (ie. Upper Coal Measures) Coals from five horizons,having abundant microspores were used, and a sixth horizon which only gave about two spores per maceration. Dulhunty's restricted range types are here used as a basis for a broad correlation of the coal measures, but detailed correlations are deferred until more detailed information is available.

In 1949, J.A. and R. DULHUNTY extended the preliminary surveys of microspore content of coals to nine localities in Tasmania, all but one of which gave good results. Four new types not seen in the New South Wales coals are described and 43 types are recorded as being common to both areas. The simple forms are again relatively more abundant than the winged ones. Limited range types are are shown to be less reliable in the Tasmanian coals than in the New South Wales coals, for correlation even on a broad basis. Instead of using the actual percentage of spores within an assemblage (from the spore counts) relative frequency based on five unequal interval classes are used for the abundance on the basis that it is a better method when only a few samples are available.

In 1949 de JERSEY investigated the occurrence of spores from the Triassic measures of Queensland (Ipswich area). Descriptions are given of 31 forms, numbered according to Dulhunty but given the prefix''T' to denote Triassic age. Some forms are considered to be identical with the Permian forms already described. No stratigraphical implications are discussed.

A paper by de JERSEY in 1951 shows a successful application of microspore correlation of coal seams in an area where normal stratigraphic methods are difficult. The area covered is of Cretaceous age but is highly folded and faulted with but few outcrops or marker horizons in the coal series. The seams vary considerably both in thickness and in section over relatively short distances. The report demonstrates the value of the systemmatic study of microspores in a group of seams, for correlation of those seams over short distances The distribution of each spore type in the samples was calculated as a percentage of the total spore content, as represented by a sample population of at least 500 spores per sample, where a sample was a reduced channel sample from the full seam. Certain types could then be picked out as characteristic of each seam, but as only 450 feet of strata were inspected having five seams in all, it is difficult to estimate the value of the types as index fossils.

In his paper on the Upper Permian coals of Collie, Western Australia, BALME 1952 aimed at discovering the stratigraphical ranges of spores in order to attempt a zonation of the coal series where lithological and normal palaeontological methods had proved inadequate. General seam assemblages were produced using 200-400 spores per count and working on percentages averaged over several localities. The resulting graphs are fairly distinctive, and give three well marked groupings of spore types which the author terms 'horizons' and a broad zonation is achieved from these results. Certain spores are found to have a restricted time range and are termed 'key types', the assemblages being made up of these and about eight other forms termed 'essential microspores'. Accessory spores are not included. The whole of the flora resembles those from the Gondwana sediments already discussed from India and Eastern Australia, one notable feature of each being the complete lack of forms larger than 150μ in diameter The relative abundance of spores in the coals is referred to the conditions under which they accumulated. Better yields of spores are found in those coals characterised by a high volatile and hydrogen content than those with a normal content of these constituents.

BALME and HENNELLY in 1955 described bisaccate sporomorphs from Australian Permian sediments including coals and shales, using the Linnaean system of nomenclature for the first time in the Southern Hemisphere (following Potonie and Kremp 1954). They recognised that the abundance and variety of bisaccate types in the Permian coals provided unrivalled material for the study of this particular group, especially from the Indian and Australian coals. The paper is concerned with the description of forms and the discussion of their relationship with their Northern Hemisphere counterparts. A discussion is included on the possible affinities of bisaccate sporomorphs, and a comprehensive synonymy is given for types previously described by Dulhunty, de Jersey and Balme in Australian work and also Virkki in Indian work. For each newly described sporomorph a type locality is stated.

During his investigation of the Corystospermacea from the Molteno Beds of Natal, H.H. THOMAS in 1933, discovered biwinged microspores in the macerations of certain of the synangia. He described the forms present, relating them to the later Caytoniales, and noted developmental features. This record shows that by early Triassic times the plant life in what is now Africa, was well enough advanced to be producing gymnospermous types of pollen, and also cuticular fragments. These plant remains although not Permian in age, justify mention here as they are the first recorded find of winged microspores, or indeed any microspores in the Karoo rocks of Africa.

The only other reference to microspores from Karoo sediments in Africa, was published by RILLETT in 1954. A limited flora had been extracted from the economically important coal seams of Dannhauser, Natal. He gave a general survey of coal spore work (in thesis form) and the descriptions of types from the poorly fossiliferous coals of Natal. Lack of spores provided insufficient material upon which to base either stratigraphical or classificatory conclusions. However, some descriptions are given (the nomenclature used being that of Schopf, Wilson and Bentall 1944 and amended independently in 1950 by Knox and Kosanke) These are the first recorded microspores from the African Permian coals, but are unfortunately from a poorly represented area as far as microfloral remains are concerned.

None of the preceding work can be considered relatively close in space, to the present investigation, but the coals are of the same period of formation. The extension of the Permian coal spore work into the remote Ruhuhu Valley of Tanganyika must therefore be treated as an observational exercise in recording all spore types encountered, and their occurrence at specific horizons, much as has been the case in the preliminary surveys carried out on the Indian and Australian coals.

The results of these latter investigations are already well established and accepted in their respective areas. In each of these regions, the formation of the coals followed a period of extensive glaciation. The glacial epoch did not terminate st the same time in each area, but the sequence of events which followed have been shown to be of a similar nature, and the macro-floras appear to have followed approximately similar trends. From the foregoing literature, it has been found that there is also a similarity on the micro-floras of the Australian and Indian areas. As the Tanganyika coals are of about the same age geologically, it might be reasonable to expect that the macro- and micro-floras would show some resemblance to those of the other areas. In actual fact, the flora as reported by WALTON in 1932 (Stockley and Walton 1932) from fragmentary remains, includes species of Rhexoxylon and Vertebraria, Glossopteris indica, some species of Gangamopteris and Equisetales stem remains ie. similar to but not as prolific as the floras of Australian and Indian Permian sediments. The meagre microspore content of the macerated Natal coal did not uphold a promise of an abundant micro-flora which might otherwise have been inferred by comparison with the Permian coal measures and their micro-fossil content as seen in India and Australia.

Therefore, it was a matter of speculation at the start of this investigation as to whether the Ruhuhu coal would follow the Natal coal in having little microfossil content, or the Indian and Australian coals in having both variety and abundance in its micro-flora.

. . . .

S E C T I O N   II

T H E   I N V E S T I G A T I O N

P A R T   I

P A L A E O N T O L O G Y

SECTION II : THE INVESTIGATION

PART I : PALAEONTOLOGY

(1) Description of Material

In the introductory section a brief outline has been given of the purpose of the Tanganyika Coalfields Investigation made by the Colonial Development Corporation. In all its aspects it was a project having as its ultimate aim the proving of an economic coalfield - hence it was a biassed investigation. To superimpose upon this an academic study of any kind, was to subject such a study to severe limitations from the outset. The most obvious of these limitations was that it was not possible to choose freely from the full range of coal seams present in the coal series, for only those of economic value had been sampled and shipped to England for chemical analysis. The study in itself has a bias to an economic end for the stratigraphical part was designed to show whether the sporomorphs could be used to identify individual seams in this particular coalfield.

The planning of the research had to be done so that there would be no necessity to utilise seams of less than three feet in thickness, or of a higher ash content than 25%. In practice this has been possible without detriment to the study, except that two thin seams have been omitted completely, not having been worth sampling in the original investigation. But as the primary object was to discover whether sporomorphs werepresent in the coals, and their subsequent description and idéntification, this was of secondary importance, until correlation of seams was considered.

Fo For the first part of the palaeontological work an incomplete 'bulk sample' from the Main Mkapa trial pit in the Mbuyura coalfield was used. It was selected in case of wastage of material in the event that insufficient sporomorphs were present to warrant the continuation of the work - or in fact if sporomorphs were absent altogether. The Main Mkapa sample covered a sequence of coals, 36 feet in thickness, and samples were selected from the top, middle and base of the section to give as wide a range as possible in so small a section. The three samples so selected represented two feet of coal each, cosisting mainly of dull,hard coal with occasional laminae of fusain and vitrain. No chemical analysis had been carried out on the coals used so that there was no accurate guide to the quality and hence to the treatment rquired to macerate the samples. As a rough indication the average proximate analysis for the Mbuyura field showed over 16% ash, about 56% fixed carbon, and 24% volatile matter.

At a later stage when the presence of sporomorphs had been proved and extracted from the Mbuyura coal, it was possible to obtain selected diamond drill cores from the Mchuchuma

Coalfield. The object of this was to extend the range of coals inspected, both in age and area, to determine the stratigraphical worth (if any) of the sporomorphs extracted, and to ascertain whether any further forms were present in this coalfield.

The Mchuchuma coals covered the four economic seams of the Coal Sandstone series, and the Mbuyura samples represented a possibly younger group of coals from the Coal Shale series of Ngaka.

(2) Techniques

(a) Sampling Techniques

(i) Pit Samples: A sample of approximately two pounds in weight was taken from the original bulk sample from the pit. Each sample was quartered to about eight ounces, reduced in size by means of a hammer, and again quartered. The remaining two ounces of fragmented coal was taken to be representative of the full two feet of coal seam from which the bulk sample was taken.

(ii) Core samples: The half cores remaining from the chemical analysis were chip sampled along their entire length removing approximately $\frac{3}{4}$" of the original $1\frac{3}{4}$" diameter of the core. About one sixth of the core by volume was thus made available for the extraction of the spores. During the analysis by the Fuel Research Staion at Greenwich, the cores had been divided into sections by inspection, giving approximately two foot lengths, each of which was subdivided into a number of smaller sections according to their physical appearance and specific gravity. In order to be able to refer back to these subsection analyses, the same subdivisions were used during the sampling, but for the actual maceration samples the subsections were recombined into the two foot sections.

(iii) Crushing: Manual methods only were employed throughout. Each sample was reduced to about $\frac{1}{4}$" size by means of a hammer. All further crushing was done with a small pestle and mortar, the samples being made to pass the British Standards mesh sizes 8, 16 and 30 successively. The fraction less than 120 mesh size was removed as its fineness impeded the maceration processes, but a sample of this dust was retained for reference.

All samples were stored in glass sample tubes of the 3" x 1" size with cork stoppers. As the maceration process depends upon the oxidation of the coal there is no necessity to store the samples in air tight containers.

To obtain a sample for maceration, the powdered coal of a sample could be quartered down until a representative sample of 1-1$\frac{1}{2}$ grams was produced. In all sampling procedure in this investigation this standardised method of crushing and

and sampling as set out above was rigidly adhered to so that samples would be comparable, and as near representative as possible of the sections of coal from which they were taken.

(b) Maceration techniques

Maceration is the chemical breaking down of coal by oxidation and removal of the resulting soluble substances with dilute alkali. Spores and other plant fragments remain almost unaffected during these reactions. Crushing the coal is only used to a grain size of about 250μ although the actual sizes of spores recoverable are between 20 and 120μ. The final release of the small spores from the coal matrix is effected by chemical means, which tends to reduce the amount of fragmentation which would occur if the crushing process were continued to this small size of grain.

Several methods of maceration have been applied to coal by various workers, the most usual being that used by Raistrick in 1933 entailing oxidation with Schultz solution (ie concentrated nitric acid in which crystals of potassium chlorate have been dissolved) and the removal of the ulmins so formed by dissolving them out in dilute alkali, (either sodium or potassium hydroxide in a 5% solution.) A second method, claimed to be less severe in its treatment of the spores, is that devised by Zetsche and Kalin in which the powdered coal (only about .25 gms.) is oxidised with fuming nitric acid and then cleaned by using first concentrated nitric acid, and following with progressively less concentrated acid until the final wash is with distilled water. Hydrofluoric acid may be used as a macerating agent on its own or in conjunction with either of the two methods described above. It is valuable where the coal contains a high proportion of mineral matter.

No hard and fast ruling can be made as to which method of maceration is to be used with which coal. Each research worker favours his or her own method, dependant upon such factors as type and quality of coal, facilities available and experience of the type of residues produced by the various methods.

The Tanganyika coals, being high in ash content and of a rather hard nature, were found to require more than the simple treatment with Schultz solution or by the Zetsche and Kalin method. each of which produced some spores from the first maceration together with a high proportion of opaque matter - clean residues of almost pure spore material have been found difficult to produce. The following standard method has been found satisfactory and is set out as that procedure by which all the Tanganyika specimens have been treated unless otherwise stated. Even after considerable experience some samples failed to produce clean preparations.

(i) 1 to $1\frac{1}{2}$ grams powdered coal was covered with concentrated hydrofluoric acid, in a polythene container, and left for 48 hours to soften the coal and to remove as much mineral matter as possible before maceration. The sample was then washed thoroughly and partly dried before treatment with the Schultz solution.

(ii) The sample was transferred to a 50 ml. glass beaker to which was added $1\frac{1}{2}$ grams potassium chlorate per gram of coal. To this was added 15 mls. concentrated nitric acid, care being taken that the sample did not become overheated and 'spit'. The time required for the oxidation of the coal varied between 24 hours for a weathered outcrop sample, and up to 48 hours for an unweathered borehole core sample.

(iii) After wahing well to remove all traces of acid, the oxidised coal was transferred to a 250 ml. beaker and about 50 mls. of a 5% solution of Potassium hydroxide was added and the beaker well agitated. The solution was diluted after 24 hours and the now full beaker allowed to stand for a further 24 hours, during which time the residue containing the spores would have sunk to the bottom so that the liquid on the top could be decanted without disturbing the spore residue. It was found necessary to wash the residues by repeated addition of water and allowing the mixture to settle in this way a further four times at least, in order to remove all traces of the brown liquid formed when the dilute alkali was added. A centrifuge having paired 50 ml. tubes eventually cut the time involved in the washing process to roughly an hour's work after the first decantation of liquid.

(iv) Concentration of the spore residue was effected either by decanting or by means of the centrifuge when this became available. In each method any fragments of unoxidised coal still remaining in some samples were removed at this stage and the remaining residue of spores and plant fragments were put into 3" x $\frac{5}{8}$" glass specimen tubes. When stored for a long period of time formalin can be added to prevent the growth of moulds, and the tube sealed with paraffin wax. In normal practice this is not usually necessary as the samples may be of a temporary value only.

(v) The final process is the staining of the preparation as an aid to identification, for spores are not as plentiful in the Ruhuhu coals as in the more extensively studied British coals where no staining is done. The stained spores are more easily distinguishable from the ground mass than the almost transparent unstained spores. A few drops of saffranin stain are added to the tube of residue and left for several hours before the preparation is used.

(c) Microscopical techniques.

For mounting purposes, ~~a~~ prepared glycerin jelly was used - a small amount of the stained residue was put into a watch glass on a thermostatically controlled hot plate. Some of the water was evaporated off and a drop or two of glycerine added. A small piece of glycerine jelly was added and then left to melt. The residue was well mixed with the glycerine and jelly and a few drops transferred to a No 0 cover slip which was at the same temperature as the mixture. This could then be inverted on to a warmed slide, and cooled gradually. When the slide had set, the cover glass was sealed to prevent any absorption of moisture from the air by means of 'Glyceel'. From each residue, three slides were made; two for use in general scanning for identification of types, the third for checking that no further types were present. The two former slides were those used for stratigraphical spore counts.

A subsequent improvement in mounting technique was found to be the melting of the glycerine jelly in a water bath prior to its addition to the warmed residue, the actual mounting being carried out as before.

For all investigation purposes a Cooke Troughton and Sims petrological research microscope fitted with a detachable mechanical stage was used. With high intensity lighting a magnification of 500 or 1,000 was utilised for identification and description of sporomorphs. Measurements were carried out by means of a micrometer eye-piece.

The techniques here described are based on methods used and described by research workers on both Carboniferous and Permian coals in Western Europe, U.S.A., India and Australia. However, the methods have been standardised for use on the Ruhuhu coals after extensive experimenting on times and on proportions and quantities of reagents to produce the desired effects on the material. Even so it was found difficult to prepare anything that could be termed a 'concentrate of spores' as described in the literature. It was found that concentrates, as yielded by British material giving several thousands of spores on one slide, were in direct contrast to the sparser preparations of Ruhuhu coals where a slide containing one thousand spores could be considered an exceptionally good preparation, while more normal preparations are in the region of three to five hundred spores per slide.

(3) Morphology and terminology in the identification and classification of fossil sporomorphs

The identification of fossil sporomorphs is largely based on their physical features ie. their morphology. In the absence of any other evidence it is the morphology which must form the basis of classification of the fossil members of the group of organisms which includes spores and pollen grains. Only when modern types are being investigated can the actual affinities of the organisms be utilised in the classificatory process.

Sporomorphs are formed in tetrads from the spore mother cells, and may be either in the form of bilateral or tetrahedral tetrads. The former have an inherent bilateral symmetry (which may or may not be obscured) and possess a longitudinal scar of dehiscence. These forms are termed 'Monolete'. The tetrahedral arrangement of spores in the spore mother cells gives rise to a radially symmetrical type of sporomorph having a somewhat triangular area of contact which result in a triradiate scar of dehiscence. The shape of these latter forms can vary from circular to triangular and are normally preserved in a flattened disc. They are termed 'Trilete' - the triradiate scar appears on the proximal side of the spore, the opposing pole being the distal pole, and the margin bounding the spore between the two poles is the equator. It is found in practice that there is a distinct preference for the sporomorphs to be flattened in the equatorial plane so that most views of them are either proximal or distal. Side views are rare in trilete sporomorphs, although quite common in winged forms where the air sacs are in the proximo-distal plane.

Pollen grains - instead of being equipped with scars of dehiscence have a combination of pores and germinal furrows. The early forms such as are found in the Permian, appear to have only a longitudinal furrow or weaker area of exine (outer spore coat). The so-called primitive pollens which occurred in the Palaeozoic are generally of the coniferous type having air bladders, and are usually flattened to give a side view.

A further general group of fossil sporomorphs is provided by the group having no visible slit of dehiscence or germinal furrow. These are termed 'alete' and may be easily confused with monolete forms in which the scar is obscured, and in this work are treated as monolete forms.

Of the other possible morphological features only the spore coat or exine is preserved, there being no evidence for the distinction between the unicellular spores and the multicellular pollen grains. The exine is usually ornamented in some way (sculptured is the term used for modern pollen) although it may be completely smoooth in some forms. The ornament can be considered for ease under two main groupings - those types of ornament formed by the protrusion of part of the exine or by growths on the surface, and those types formed by some form of indentation of the exine. In envisaging these main groupings it must be remembered that this is a purely descriptive division based on the appearance of the ornament in the mature spore and not on the mode of origin of the sculptural elements. A further distinguishing feature related to ornamentation types, is the presence of equatorial or marginal attachments in the form of bladders, and flanges (spores) and air sacs (pollens).

Relative size of the ornament in relation to the size of the spores is variable. It is by no means uncommon to find a small spore with a relatively coarse ornament or a large spore with a fine ornament. It has been noted with interest that the sporomorphs from the Ruhuhu coals have the tendency to be relatively small - no really large forms, including the bladder in the spore, have been found. Nor have the coarser types of ornament been seen in the forms present, the sculptural elements normally being less than $3/^{u}$ in any direction. This fact is in direct contrast to the Carboniferous types of the Northern hemisphere where relatively small spores may have a reticulate ornament of dimensions greater than $3/^{u}$.

Ornamentation, being the variable feature upon which most of the classificatory work is based, has been accorded a place in all the literature on spore classification. Many terms are used loosely and different authors favour different terms. Definitions of the terms used appear to vary from one author to another, and it would seem that a certain amount of overlap must occur where there appears to be a gradation from one ornament to another as frequently the size range of the element is only vaguely mentioned. The terms used for describing ornamentation types are therefore given here with a definition of the term. Certain terms are included for definition which have not actually been encountered in this study but are given for completeness. The definitions are based on those given by Potonie and Kremp (1954) Kosanke (1950) Faegri and Iversen (1950) and Erdtman (1947). The actual terms used are those which the present author favours for their descriptive value, the alternatives being mentioned where relevant.

Group I - Ornament absent, exine smooth or nearly so.

PSILATE - having smooth surface, ornament absent or so fine as to be barely distinguishable, thus including minute punctae and granules of dimensions less than ½/^{u}. (Laevigate)

Group II - Ornament raised above the surface of the exine.

GRANULATE (-ose) - having small rounded protruberances or granules ranging from about ½-1½/^{u}. (ie. fine to coarse) may be irregularly or regularly arranged; having circular outline in plan and semi-circular to nearly circular side view.

VERRUCATE (-ose) - having large granules of which one dimension in plan is greater than or equal to 2/^{u}. The outline in plan may be regular (circular) or irregular; in side view similar to granules. A close set irregular verrucate ornament can produce a negative reticulum.

TUBERCULATE - having blunt tubercles with a flattened or rounded cross section; can be short or long (1-6/^{u}) with rounded ends (true tubercles) or flattened (setae). Compound types may occur showing distal division or several elements joined laterally (cristae).

SPINOSE (Echinate) - having spines with distinctly circular cross sections, and terminal points (coni); length and diameter at base variable from ½ - > than 2/^{u} diameter, and 1 - 5/^{u} in length. A compound spinose element is recognised in which the base resembles a verruca of approximately 2/^{u} diameter, and is surmounted by the normal pointed cone.

'STRIATE' - An unusual ornament, apparently formed by the alignment of granules into ridges and having furrows between. The ridge may reach up to 3/^{u} in width, although the granules are only up to 1½/^{u} in diameter.

Group III - Ornament depressed into surface of exine.

PUNCTATE - having punctae between ½ and 1/^{u} diameter. Not easily distinguished from psilate on the one hand or microreticulate on the other and may grade into the latter.

MICRORETICULATE - having depressions or luminae in the surface of the exine varying in width from 1 - 3/^{u}; ridges or muri of exine between luminae. If the ornament is fine and close set it is indistinguishable from punctate. On first inspection under the microscope, the general appearance may seem to be granular, but with careful focussing the distinction can be recognised. It is almost a 'negative granulate' ornament. Can be either regular or irregularly arranged with regard to the lumina.

RETICULATE - having a reticulate ornament of luminae and muri in which the former are of greater diameter than $3/^{u}$ and the latter become broader. Larger versions are Foveolate and Areolate.

VERMICULATE - having an irregular form of ornament varying from an irregularly broken reticulum with the muri remaining as isolated patches variously described as scrobiculate, and inverse reticulate.

RUGOSE - having broken reticulum in which the remnants are tending towards parallel , irregular arrangement is canaliculate and tends towards obervermiculate and finally a true striate type.

Identification of ornaments under the microscope.

The identification of each of the ornamental types depends to a certain extent on recognising at what level in the surface of the exine the objective is focussed. It is for this reason that granular and microreticulate ornaments are easily mistaken for each other, one being the negative form of the other. However, there is a definite sequence to the appearance of any feature in the exine and a distinction can easily be made on focussing up and down on the specimen. This is dealt with in detail by Faegri and Iversen (1950) and Erdtman (1943) for recent pollen. On first focussing down on any protuberance from the surface it appears as a light patch, while the background which is still out of focus remains darker. On continuing to focus down, as each part comes onto focus it appears lighter than the rest, whether above or below. Hence the first view of a granular ornament is of small light spots on a darker background, and on focussing down this will become a light background with darker spots on it. The reverse is true of a microreticulate ornament which on first coming into focus will appear as darker rounded patches with lighter ridges between and further down will give the impression of light patches on a darker ground. A description of this feature is given in Potonié and Kremp (1954).

(4) Classifications of fossil sporomorphs

In the absence of any evidence of relationships between fossil sporomorphs, or of their affinities to the macro-flora existing at that time, the problem of classifying them into natural groups becomes a real problem. In normal classificatory work account is taken not only of the appearance of the organism in question but also of its relationship to other similar organisms, and to its systematic place within the animal or vegetable kingdom.

But fossil sporomorphs present a different kind of problem, for it is rare indeed that the affinities between these organisms and the parent flora are known. In fact, far more types of sporomorph are found in certain deposits than identifiable species of plant. This is especially true of the Ruhuhu material where macro-remains are sparse, consisting of fragmentary remains of Glossopteris indica, Gangamopteris spp., Vertebraria sp., and Equisetalean stems while the number of varieties of sporomorphs in the coals may reach 30. An aspect which may easily be overlooked in classification is that the sporomorphs are generally studied on their own - ie. not in relation to the macro-flora or any other remains. One tends to be concerned with one aspect or the other, but rarely with the problem of correlating micro-organisms with their parent plants or in relation to other fossils - possibly because of the specialised extraction techniques. In any case, unless fertile fronds are present there can be no correlation between micro- and macro-flora.

It can be seen that no true natural classification can be made for sporomorphs, in their fossil state due to lack of information. But it can be suggested here that in view of the stratigraphical use to which these organisms are put, lack of natural classification is no great obstacle. In fact, a sporomorph correctly described and figured so that it can be identified easily and accurately by others, is of far greater value than one that is merely named and classified according to a 'natural system'. This then is the object of this section of the work - to provide descriptions of the sporomorphs encountered for future reference although it is found to be convenient to arrange them in some sort of logical order, even though this cannot be a natural classification. Not until a vast amount of further work is completed will it be possible to hazard more than a guess at the affinities of these sporomorphs, and the significance of the development of such features as flanges and air sacs, which distinguish the modern coniferous types of pollen from other groups. These are some of the interesting features of the sporomorphs of the Permo-Carboniferous floras of the Southern hemisphere. Here again, it would be dangerous to compare the newly encountered forms of the Ruhuhu material straight away with those similar forms found elsewhere, for much more detailed work is necessary on both sets of material before such conclusions can be drawn.

The types of classificatory methods used by workers on fossil sporomorphs fall into three groups:

(a) Linnaean nomenclature being the binomial system in use for normal classificatory work - a natural system of classification where related forms appear in related groups, which is dependent upon knowing affinities.

(b) Binomial nomenclatural system in which the terminology is descriptive, and based upon visible features, not on affinities and in which superficially similar forms occur together although no evidence is available for this grouping.

(c) Schematic classification in which types are designated by an artificial scheme of letters and numbers, and grouped together on visible features.

In all three systems, no allowance can be made for similar forms of different parentage being grouped together, nor for differing forms of the same parentage being separated (eg. developmental stages as shown by MOORE 1946 may exhibit several distinct forms during growth) unless the parent plant can actually be identified with its own sporomorphs adhering to it.

(a) The Linnaean System is the accepted form of binomial nomenclature and depends for its value on known or inferred affinities and the ability to be able to put related forms into related groups. Its shortcomings with reference to fossil sporomorphs is obvious, in that relationships cannot be proved and hence it is based upon assumptions and comparisons with modern groups. The use of a classification for sporomorphs separate from that of the parent plant is unsound in some respects for it accords to them the full status of a plant group instead of regarding them as part of the life cycle of some more advanced form. However, even if the modern groups of spores and pollens can be treated as part of the parent plant and classified accordingly, this is not so for the fossil representatives of these groups, as already mentioned. The only method of subjecting the whole group to the same taxonomic treatment under the Linnaean system would be to treat them as an independent group of organisms for the purposes of classification, but not without reference to affinities where known.

It is noticeable in spore work, that it is only after an extensive background of investigation has been carried out that the Linnaean system of nomenclature has been adopted. The use of binomial nomenclature was restricted in the earlier investigations to isolated remains. As each stratigraphical group of spores came into the limelight they were classified into a numerical system eg. Raistrick 1933 etc. But since 1945 the practice with Northern hemisphere research workers has been to assign generic and specific names to the spores and to group them together into what are believed to be 'natural groups'. Much research was done in the course of this transference to the Linnaean system, on modern forms and their relationships with Palaeozoic forms (Knox 1950). The result is that, in just over 20 years of spore study in Western Europe and the USA, there has developed a complex nomenclature, and classifications have been put forward by one author or another only to be superseded and amended by a later and more comprehensive work. Western Europe then suffers from a surfeit of classifications in which the latest and most comprehensive monograph is only partly published as yet! (POTONIE and KREMP 1956) the previous nomenclature in use being due to SCHOPF, WILSON and BENTALL 1945, KOSANKE 1950, KNOX 1950 and POTONIE and KREMP 1954.

So far in the Permian spore world only one group of sporomorphs have, as yet been transferred to the Linnaean system of nomenclature, and that after one author had had experience of the British Carboniferous spores (BALME and HENNELLY 1953). From the outset, however, the genus Pityosporites had been treated separately probably because of its advanced form, and easy recognition.

The tendency now appears to be to use an easier form of designation for the spores in the initial stages of the investigation and to turn gradually over to the Northern hemisphere nomenclature as experience is gained in recognition and comparison of material.

(b) Descriptive nomenclature: has been used by some workers on Permian coals, to give a complete classificatory system for all spores and pollens regardless of geological age or botanical affinities.

In 1937 NAUMOVA devised a descriptive scheme of nomenclature to embrace all fossilspores and pollens based on previous work by LUBER and WALTZ (1935). The primary emphasis is laid upon the genetic features where visible ie. the nature of the tetrad scar, or germinal area. Sub-divisions are made on the visible morphology such as shape and ornamentation. The scheme is not much in use possibly because of the difficulties involved in obtaining the original literature and specimens for comparison, but it has been followed by subsequent USSR workers and is sometimes used by Indian workers. Some of the divisions, and generic names have been incorporated by priority in the POTONIE and KREMP classification.

In 1954 PANT used NAUMOVA's classification as the framework for a completely new schematic classification to cover all fossil and recent spores and pollen grains. It is a rearrangement of NAUMOVA's work with references to ERDTMAN's paper of 1947, and essentially morphological for use on fragmentary remains, but lack of supporting diagrams means that he has only succeeded in creating a large number of 'nomina nuda'. The result is that most workers have bypassed this paper and used the same or similar names for different specimens.

The 'sporomorph - sporotype' classification presented by ERDTMAN in 1947 seems to have been produced with the object of providing a classificatory system which could be universally used for fossil and modern sporesand pollen grains, without reference to their parent plants, although this information can be taken into account in the actual naming when known: ie. a scheme into which any spore or pollen grain can be placed on purely morphological grounds.

The primary divisions (Caenotypes) are made on the nature of the dehiscence aperture. Fossil spores fall into the groupings C2 - Non Aperturate, C 10 Saccites, and C 11 Laesurate (Monolete and Trilete forms). Sub-divisions are made on shape and ornament, and the resulting 'shape group' or 'SPOROMORPHAE' are given descriptive names or a name which acknowledges affinities where known. The sporomorphs may be subdivided into forms within the 'shape group' and consist of several distinct forms with certain basic features in common. But it can be seen that no provision can be made for differing sporomorphs of the same parentage to be classed together or for similar sporomorphs of differing parentage to be separated. The typical 'central' member of a sporomorph is termed a 'SPOROTYPE'.

This classification is therefore an attempt

(i) to achieve a fairly natural classification into which any form can be placed, and given a Linnaean type name.

(ii) to give fossil spores and pollen grains full status as microfossils, without losing sight of the fact that affinities of many, although at present unknown, may subsequently be discovered.

and (iii) to provide a classification, which, although schematic, has full scope for further variation within the known Caenotypes, and for the addition of further Caenotypes if research warrants them.

(c) <u>Schematic classification</u> has been the most varied and most widely used method of grouping fossil sporomorphs in the initial stages of an investigation.

The system created by RAISTRICK (1933) was used by Northern hemisphere workers extensively until 194~~5~~4 when SCHOPF, WILSON and BENTALL published their paper. In fact some of the original spore types are still known and described under the RAISTRICK numbering when used in stratigraphical problems in the British Carboniferous.

The Indian workers have two current classifications in general use dependent upon the material investigated. That of VIRKKI (1945) is a theoretical form of classification in which numbers only are used to designate types. Unless all possible types of spore have already been discovered and described this numbering makes for rigidity and new types could only be added with difficulty. The primary divisions in this classification are based upon the presence or absence of wings, and further sub-division takes place on the nature of the tetrad scar, or germinal area. The first division is presumed to be a natural division, for winged forms are taken to be of a more advanced nature than those without. Purely morphological features such as shape, size and ornament take second place to the genetical features in the sub-division of the groups. Much attention is paid to the winged groups which are both abundant and diverse in the Indian coals.

GHOSH and SEN (1948) produced a separate classification although concerned with the same age coals (but independently). Primary consideration is again given to the presence or absence of wings, type of wing or shape of unwinged body - tetrad scar takes second place. Ornamentation and size are used to limit groups. Each ornamentation group is given a letter, and the spore types within the group are denoted by suffixed numbers. The drawback in this classification is that it does not consider the tetrad scar as of prime importance, which would surely give a ~~near~~ more natural classification than that based solely on morphological features.

The Australian schematic classification was devised by DULHUNTY (1945) and has been followed until recently by all the Australian research workers on coal spores. Nowadays it is gradually being replaced by the Linnaean system of nomenclature, for instance in the paper by BALME and HENNELLY (1953). Papers following the DULHUNTY system include BALME (1952), de JERSEY (1949, and 1946). The spore groups are based upon physical features and set out in a tabular form to act as a key to types. Two sets of features are used - shape and tetrad scar together, and ornament (which includes the presence or absence of wings). Each shape group (more or less corresponding to ERDTMAN's 'sporomorphae') is denoted by a number and each spore type within the group is denoted by a letter, having been separated by size and general appearance the whole being set out as a grid. A prefixed letter is used to denote the age of the sediments from which the spores were extracted, ie. T - Triassic, P - Permian.

The disadvantage of this scheme as it stands, lies in the actual arrangement of the groups, for it would seem better to place similar forms in adjacent groups, or to put all trilete or all monolete forms in close proximity, The present arrangement leads to a lack of flexibility and the failure to allow for gradations between groups. It would be difficult to add new groups as the numbering is consecutive, although within a group additions are easy enough. For use on the Australian Permian coals, however, it has proved a workable system.

(5) <u>Classificatory problems for spores from East African Coals</u>

From the foregoing summary, the difficulties facing a new worker on Permian coal spores can be envisaged. A single standard and accepted classification for spores and pollen would be easy to accept and follow, but the fact that there can be such diversity of methods already in use and accepted as workable systems is difficult to understand. In India, for example, not only were two independent schemes of classification devised but both are in use simultaneously. Reference is also made to NAUMOVA's work and her nomenclature for spores, and this is superimposed upon the work of PANT! The spore types recorded from the Permian sediments of Australia appear to be similar to those recorded from India, but little work has been done on the correlation and synonymy of the spores from the two regions.

The Western European and American research workers with at least 25 years of experience of spore studies to their credit, can be expected to have a wealth of information and experience on which to base their more complex classifications. But here again there is a certain amount of dissention as to who is the authority to follow, although attempts are always being made to have agreement on the classification which is in current use. The latest work, in actual fact, is the one which is at present used ie. POTONIE 1953 et seq.. The USSR does not conform to the general rule of acceptance of POTONIE's work as instead NAUMOVA, LUYBER and WALTZ are accepted as authorities.

In each country however, the initial work has been based on schematic divisions of the spore types, although in many cases the naming and describing of spores has been done before enough experience has been gained in the identifying of spores and comparing them with similar forms from other areas, or enough time has been spent in comparing newly recorded types with those recorded elsewhere. For it is hardly justified in giving exactly the same name to similar spores whose recorded localities are separated by several thousands of miles of land and sea with no evidence in the intervening area that there is any connection between these areas.

It is with these points in mind that the problem of classifying the spores found in the Ruhuhu coals of Tanganyika has been approached. The experience of previous workers must be taken into account in the methods used and the descriptions and synonymy of the spore types encountered. The limitations of working on a coal from an isolated region must be faced, and hence no assumptions based on the Indian and Australian material can be made.

The natural starting point would appear to be the recognition of the value of an arbitrary scheme of classification in the first instance. This method is more flexible than the binomial nomenclature of the Linnaean system and less binding until the necessary experience has been gained for the second stage ie. the actual naming of the spores.

The next consideration is whether any of the existing schemes of classification are suited to the author's needs or whether it would be advisable to erect a further schematic classification, based on the better features of existing ones, but devised purely for use in the initial stages of the investigation of East African material. The latter course was finally chosen, partly because of the isolation of the area under investigation, and partly on the grounds that none of the existing schemes were wholly workable for these coals. However, it must be stated that it was originally based on Dulhunty's 'grid' scheme, but reorganised and revised, and benefit gained from the Indian schematic systems, to give as near natural grouping as possible.

A further consideration was whether there was in existence a comprehensive scheme of classification of spores and pollens by some authoritative worker, into whose scheme this newly devised one would fit when it was required to make the necessary adjustments for using names instead of numbers for the spores. The most obvious authority to follow was ERDTMAN who published his comprehensive classification of recent and fossil spores and pollen grains in 1947. This scheme has been used as the background and the groupings of the sporomorphs into Caenotypes taken as the major divisions of the classification. The term 'sporomorph' has been adopted from this work as a more usable term than microspores and isospores.

The new system is an attempt to present the sporomorphs in an easily classified scheme, so arranged that any sporomorph encountered can be quickly and accurately placed in its relevant group. The 'grid' layout has been designed so that apparently related groups of spores are adjacent as far as possible - however a fully comprehensive scheme on this basis would need to be three dimensional! Each compartment in the scheme represents a 'shape group' of Erdtman, and may comprise one or several distinct forms.

(6) Schematic Classification of Sporomorphs from the Ruhuhu Coals

The following schematic classification has been devised for use with the Ruhuhu material. It incorporates the group names of Erdtman's system of sporomorphs where applicable. The major divisions of the spore forms into groups is based on their physical features.

(i) The presence or absence and nature of the dehiscence mechanism.

(ii) the shape and form of the spore ie. simple or saccate.

The subdivisions based on the ornamentation yield the actual shape group or 'sporomorphae' and may be regarded as genera or parts of larger genera. Each sporomorphic group can be subdivided into 'species' on the basis of size and microscopic appearance.

Thus each number in the scheme represents a sporomorph or part genus, and each of the lower case letters applies to a distinct form within a group or 'species'.

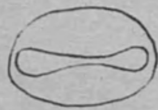
No sporotypes have been described, but following the actual classification is a detailed description of each of the spores recognised. In every case the measurement of forms has been carried out at a variety of horizons, and an average calculated for the dimensions where numbers permitted. These

Fig. 2.

Monolete Forms

2a

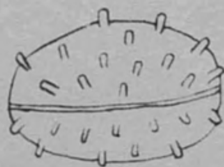
3a



3b

4a

5a

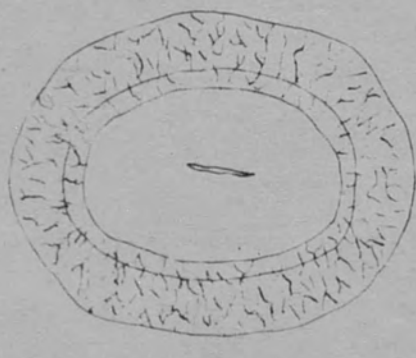


6a

8a

7b

7a



31a

50 microns

dimensions and the typical features have been summarised in the idealised diagrams accompanying the classification (Figs 2-6). The diagrams represent what are believed to be the average characteristics of a group, and the form so depicted, is a theoretical form occupying the central position for variation within a group. With further work a collection of sporotypes could be described, basing the type description on a spore of dimensions as near to this average as possible, but it is felt, that so far, not enough material has been examined nor enough experience gained by the author in the identification of sporomorphs from other areas to permit this to be done at this stage of the work. The material itself is of limited value only, for it by no means covers the whole of the coal sequence of the area.

(a) Classification of Ruhuhu sporomorphs

CAENOTYPE 2: Non-aperturate Erdtman 1947

GROUP I: ALETE

Having no visible slit of dehiscence. (So little material has been investigated that it is not felt that enough is known of this small group.)

CAENOTYPE 11: Laesurate Erdtman 1947

GROUP II: MONOLETE [Monolites Erdtman 1947 - with one laesura]

Having monolete slit of dehiscence.

1. Vermiculate, alveolar etc..
2. Reticulate to microreticulate
   a. ellipsoidal, irregularly microreticulate.
3. Psilate - smooth and minutely punctate
   a. bean shaped, suture closed
   b. ellipsoidal, suture open
4. Granulate - having small distinct granules
   a. ellipsoidal, suture obscure
5. Verrucate having distinct verrucae
   a. ellipsoidal, suture obscure, verrucae irregular
6. Tuberculate - having setae
   a. ellipsoidal, with irregular setae
7. Spinose - having pointed spines
   a. ellipsoidal, distinct spines, suture visible
8. Striate - longitudinal striae apparently formed by the alignment of small granules.
   a. large, ellipsoidal, having no known slit of dehiscence

GROUP III : TRILETE [Trilites Erdtman 1947 - having three laesurae]

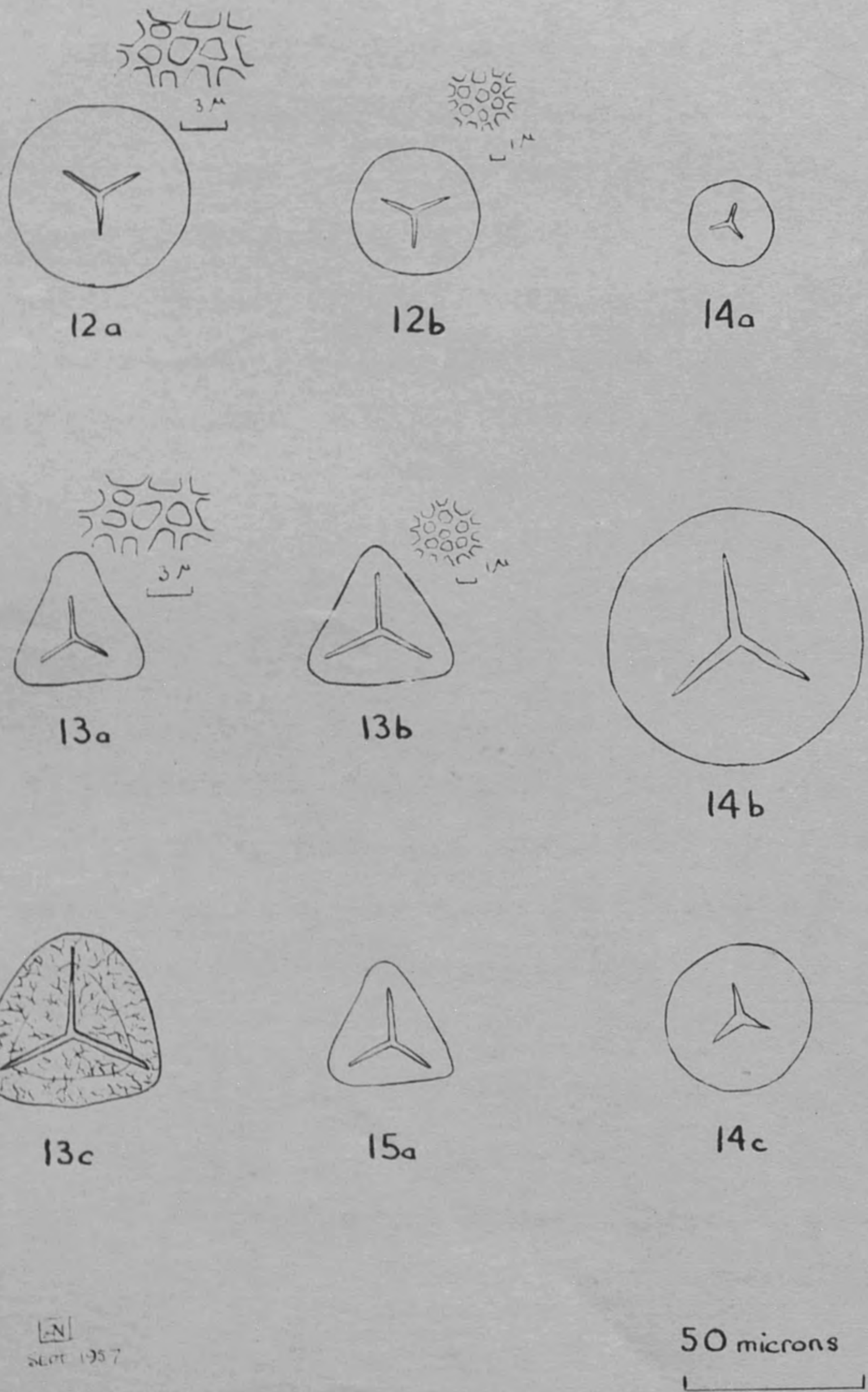
Having triradiate slit of dehiscence

10. } Vermiculate and alveolar
11. }

Fig. 3.

Trilete Forms

I. Microreticulate and Psilate



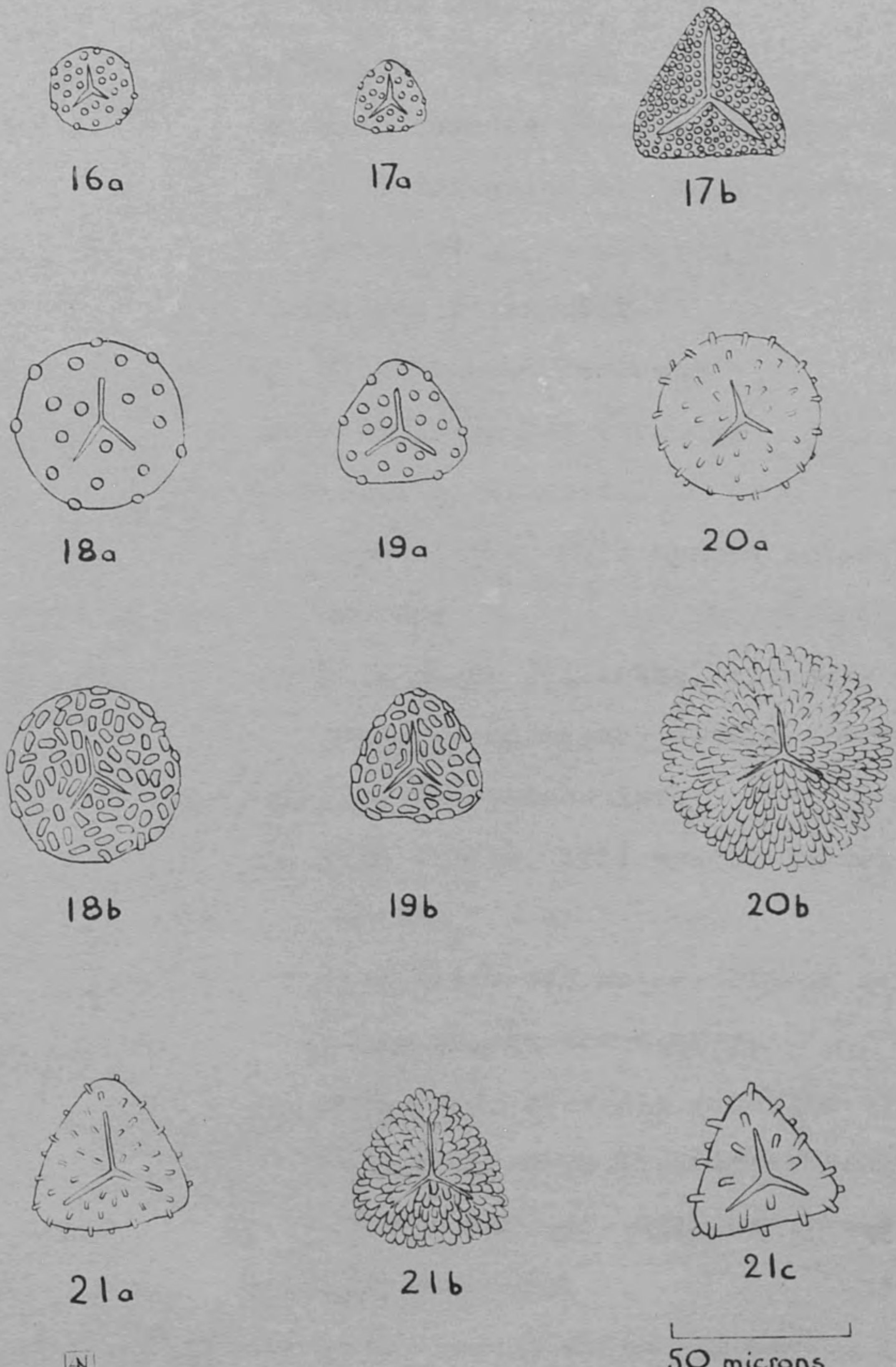
LN
Sept 1957

12. Reticulate to microreticulate; discoidal
    a. irregularly microreticulate, ornament $1-3/^{u}$
    b. regularly microreticulate, ornament less than $2/^{u}$ includes punctate ornament
    c. elongated, oval, irregularly microreticulate, ornament from $2-4/^{u}$
13. Reticulate to microreticulate; triangular
    a. irregularly microreticulate.
    b. regularly microreticulate
    c. microreticulate, having distinct outer and inner layers, suture appears to be situated in the outer layer and to extend beyond the inner body.
14. Psilate and finely punctate; discoidal.
    a. small, c $25/^{u}$ diam., suture distinct
    b. large, c $75/^{u}$ diam., suture distinct
    c. medium,c $40/^{u}$ diam., suture distinct,but short. this form is more dense than the previous pair and may be punctate.
15. Psilate and finely punctate; triangular
    a. medium size, distinct suture, almost transparent
    b. medium size, rather dense, suture distinct
16. Granulate; discoidal
    a. small with discreet granules, suture distinct

FIG 4.

TRILETE FORMS

2. GRANULATE, VERRUCATE, TUBERCULATE

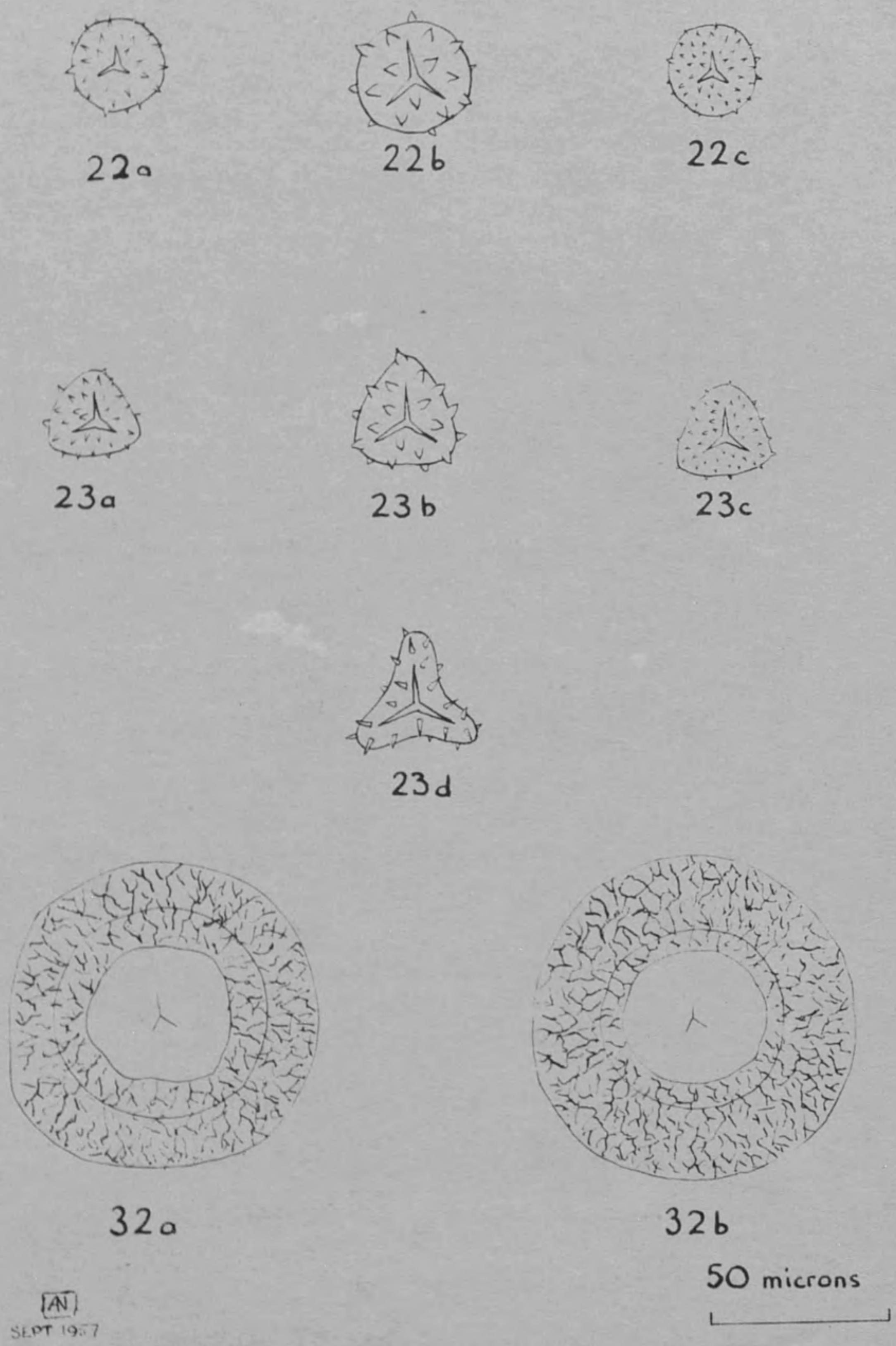


17. Granulate; triangular
    a. small with discreet granules, suture distinct
    b. medium size, with closely packed granules, suture petalloid
18. Verrucate; discoidal
    a. with rounded verrucae, suture obscure
    b. with irregular shaped verrucae, suture obscured
19. Verrucate; triangular
    a. with rounded verrucae
    b. with irregular verrucae
20. Tuberculate; discoidal
    a. with simple, well spaced setae, suture visible
    b. with close set setae, either simple or compound (cristae) suture obscure
21. Tuberculate; triangular
    a. with simple, well spaced setae, suture visible
    b. with close set setae, either simple or compound, suture obscure
    c. with long, sparsely arranged blunt tubercles (which may have divided extremities), suture distinct, open or closed
22. Spinose; discoidal
    a. with conical spines of medium size, distinct

Fig 5.

Trilete Forms

3. Spinose and Monowinged



suture.

b. with large, broad based spines, suture visible

c. with minute conical spines, distinct suture

23. Spinose; triangular

a. convexly triangular, with conical spines of medium size, suture generally distinct

b. convexly triangular, with large, broad based spines, suture may or may not be visible

c. convexly triangular, with minute conical spines, suture generally distinct

d. concavely triangular, rounded apices, with conical spines of varying sizes, suture generally distinct

GROUP IV : MONOWINGED - Having complete equatorial flange or sac size range about 50 - 120/^{u}

31. Monolete ?

a. Oval with equal width flange all round

32. Trilete; discoidal

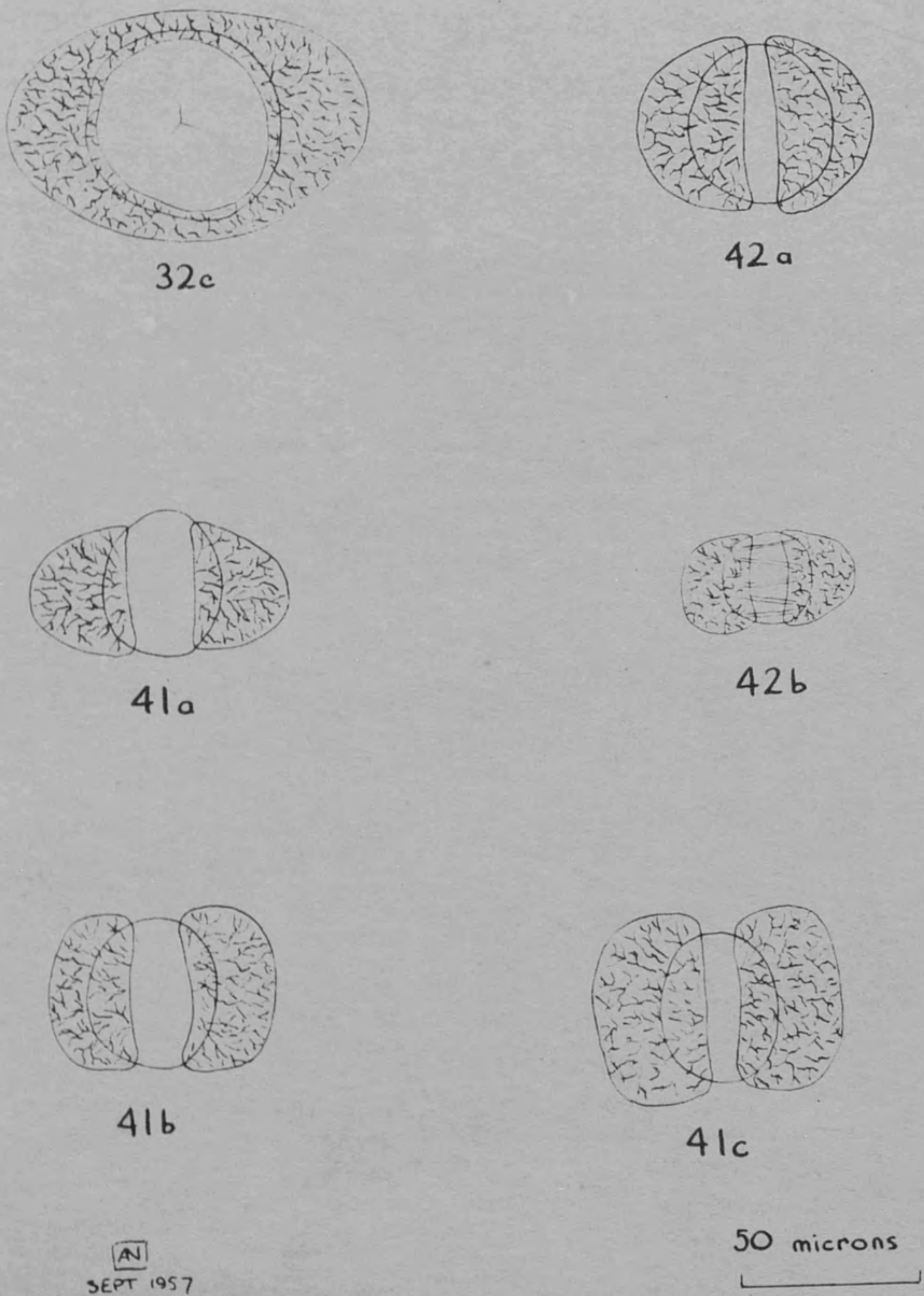
a. flange narrow in comparison to body diameter, equal width all round

b. flange borad in comparison to body diameter, equal width all round

c. spore body discoidal, flange gives apparent oval outline being broad across one diameter

FIG 6.

SACCATE FORMS



AN
SEPT 1957

and narrow across one at right angles.
probably saccate, with suture visible
occasionally

CAENOTYPE 10 : Saccites Erdtman 1947

GROUP V : BIWINGED (Bisaccate) having paired air sacs laterally placed. A form which is typical of modern gymnospermous pollen, hence tendency to call these types 'primitive pollen'.

41. Having well defined lateral air sacs.
    - a. height of wing less than height of spore body
    - b. height of wing about the same as the height of spore body
    - c. height of wing distinctly larger than height of spore body

42. air sacs not as well defined as in 41, although there may be a few obvious exceptions
    - a. spore body discoidal, wings overlap most of the body giving an apparent oval outline
    - b. spore body discoidal, wings may overlap most of the body, but may be preserved so that wings are placed at a slight angle to the body. Most characteristic feature is the presence of striate markings between the wing bases.

(b) Comparison with other classificatory schemes to give synonymy

CHART I shows the diagrammatic layout of the foregoing scheme of classification, intended to convey the possibility of gradation between the main types and the possible existence of intermediate forms not yet encountered. The grid layout allows for this in that, as nearly as possible, similar forms are adjacent to one another, although, ideally a three dimensional grid is necessary.

For the purpose of comparison with the classification and nomenclature of other authors of papers dealing with Carboniferous and Permian spores, a series of charts has been drawn up on the same grid layout as that used for the Ruhuhu coals. These classification charts are not necessarily complete being intended to show only the possible synonymy with the Ruhuhu spores, and hence may only cover the same range of spore forms and ornamentation types as those from Tanganyika.

The classification scheme for the Tanganyika coals was originally drawn up in its diagrammatic form at the end of 1954, when the value of the present layout was realised as opposed to the purely descriptive layout used by DULHUNTY. Its main use at that time was for placing newly encountered sporomorphs into an easily visualised scheme of classification.

During the following year the papers by VIRKKI (1945) and

GHOSH and SEN (1948) were treated in the same way to try and establish some connection between the type of floral constituents found in East Africa to those in the nearest related strata that had been studied in India.

CHART 5 shows that the emphasis by VIRKKI in 1945 was on the winged forms which occurred in a greater variety and abundance in the Indian coals than in those of Tanganyika. Only a few forms in the psilate verrucate, tuberculate and spinose groups showed the resemblances between the Indian and Ruhuhu coals. The winged forms from Tanganyika were similar but not the same as those from the Indian coals.

CHART 6 from GHOSH and SEN (1948) showed a greater resemblance to the Ruhuhu forms where the simple ornamentation was concerned. The lack of granulate forms in this classification is suggested to be due to the difficulties in separating them from the finely reticulate forms rather than to their complete absence (see paragraphs on ornamentation). Many more spinose forms are distinguished by the Indian workers, but these are based on fewer specimens than the Ruhuhu forms. The variety shown by the winged forms is strikingly like that of the Tanganyika material.

CHART 4 showing DULHUNTY's basic scheme, is almost the same as that for the Ruhuhu material, although the Tanganyika forms appear to be somewhat smaller in size than their counterparts elsewhere. The floral constituents of the Australian coals are, generally speaking the same as for Tanganyika, but have been subdivided into a greater number of forms, and appear in rather different proportions.

CHART 3 of LUBER and WALTZ (1935) and NAUMOVA (1937) is a more general scheme than any of the previous ones. The simpler forms can be identified from the Ruhuhu coals, although the scheme is not comprehensive enough to cover all the forms present in these coals.

CHARTS 3-6 show that these classifications are all fairly well related in their methods of selecting spore forms to be able to be superimposed upon the base layout of the scheme devised for the classification of the Ruhuhu coal apores. Hence, by this method of superimposition it is possible to compare one classification with another by direct means.

The original arbitrary classification of Raistrick has been subjected to the same procedure of breaking it up into the grid layout of the Ruhuhu classification scheme. This proved more difficult than with the foregoing ones as it consists of Carboniferous coals, and hence contains sporomorphs not encountered in the more recent Karoo material. However, CHART 2 shows the results of the reorganisation and again it is possible, to a limited extent, to find direct comparisons between spore forms. Again, there is a marked tendency for the Ruhuhu spores to be of a smaller size. Noteable in this classification is the absence of the winged forms, for in these coals, the discovery of bisaccate forms post dates the general use of Raistrick's classification. The system of numbering is still in use in this country for ease in identification of spores in stratigraphical work in the coals.

Until Potonie and Kremps' work on classification became generally known and used, from about 1955 onwards, the system of nomenclature and classification in general use was that of Schopf, Wilson and Bentall published in 1945 with revisions and additions in 1950 by Kosanke and Knox working independently in USA and Great Britain respectively.

CHART 7 gives an idea of the complexity of the nomenclature, and of the difficulties involved in breaking it down into relatively simple groupings as in the Ruhuhu grid layout. The author attempted to do this as early as 1955, but the whole scheme became so involved that it was decided to leave any attempted synonymy between the Ruhuhu spores and those genera recognised by the American workers until a much more thorough study of the problems of classification had been made. Eventually, in November 1956, the classification was broken down into its present form in the chart, affecting the previous layout of the Ruhuhu scheme. Thus the American system by its complexity has affected even the apparently simple grid scheme of the Tanganyika classification, the latter owing its final form to the Schopf, Wilson and Bentall classification.

CHART 8 has been based on the work of POTONIE and KREMP (1954) and POTONIE and KLAUS (1954) with reference also to the first volume of the Potonie and Kremp monograph published in 1956. The classification as re-interpreted by Potonie and Kremp, has incorporated priority names of groups as set up by REINSCH in 1881 and by H.POTONIE in 1893. A great deal of work must have put into the re-defining the genera and their grouping. It is striking to notice how easily this latest classification can be superimposed upon the existing grid system erected for the Tanganyika coals. The three main suites, Murornati, Laevigati and Apiculati are easily distinguished in the latter. The chart is not complete as this classification covers megaspores as well as micro- and isospores. Those included show the resemblance of spores from the Carboniferous to Trias of the Northern hemisphere and the spores from the Karroo coals of East Africa, Australia and India.

From this last chart, and most recent classificatory work, it would seem to be a natural step to take in the East African work, to compare the specimens with the Permian and Trias forms of Potonie. and Kremp, in order to place them into the nomenclatural system of these authors. This could be achieved in outline by comparison of the two charts and then the detailed descriptions. But the writer feels that not enough systematic or comparative work has yet been accomplished to take this first step towards the naming of the East African spores and the selecting of sporotypes.

SCHEMATIC CLASSIFICATION OF PERMIAN SPOROMORPHS

FROM CERTAIN COALS IN THE RUHUHU COALFIELDS OF TANGANYIKA

CHART 1.

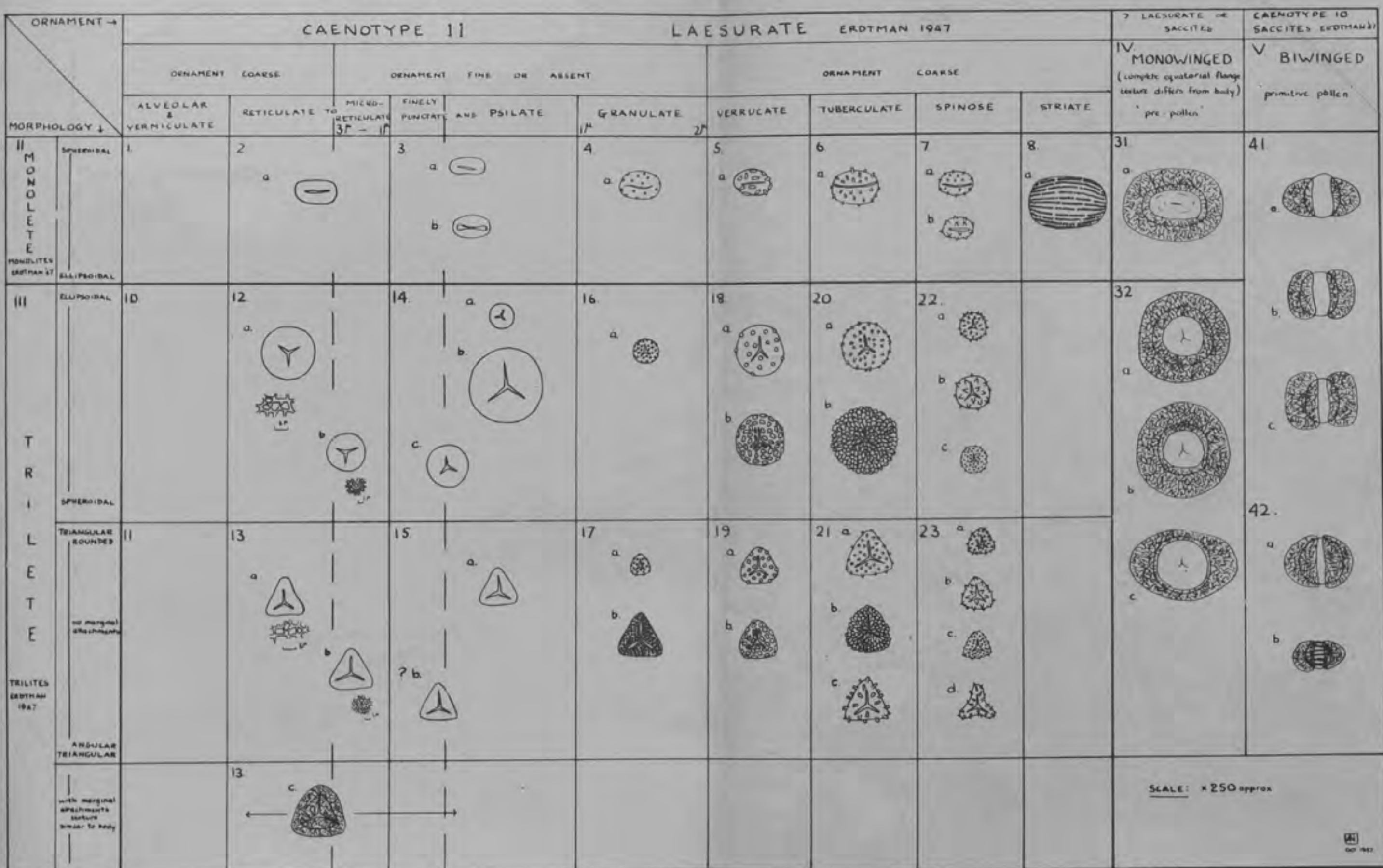


CHART 2

CLASSIFICATION OF SPOROMORPHS - BRITISH CARBONIFEROUS

RAISTRICK 1933, 1934, 1937, 1939 AND KNOX 1947

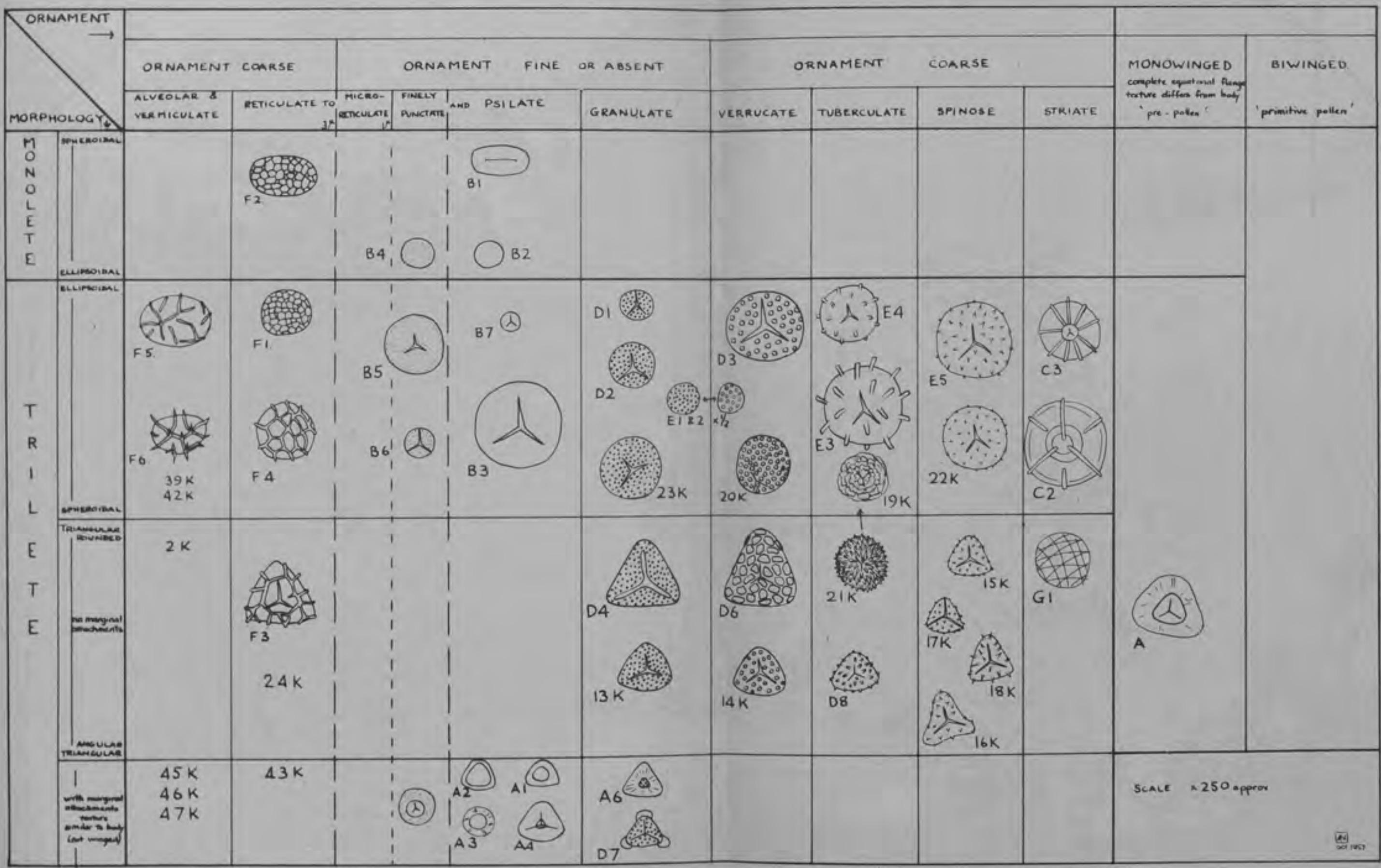


CHART 3

CLASSIFICATION OF SPOROMORPHS - U.S.S.R. PERMO-CARBONIFEROUS

NAUMOVA 1937, LUBER & WALTZ 1935

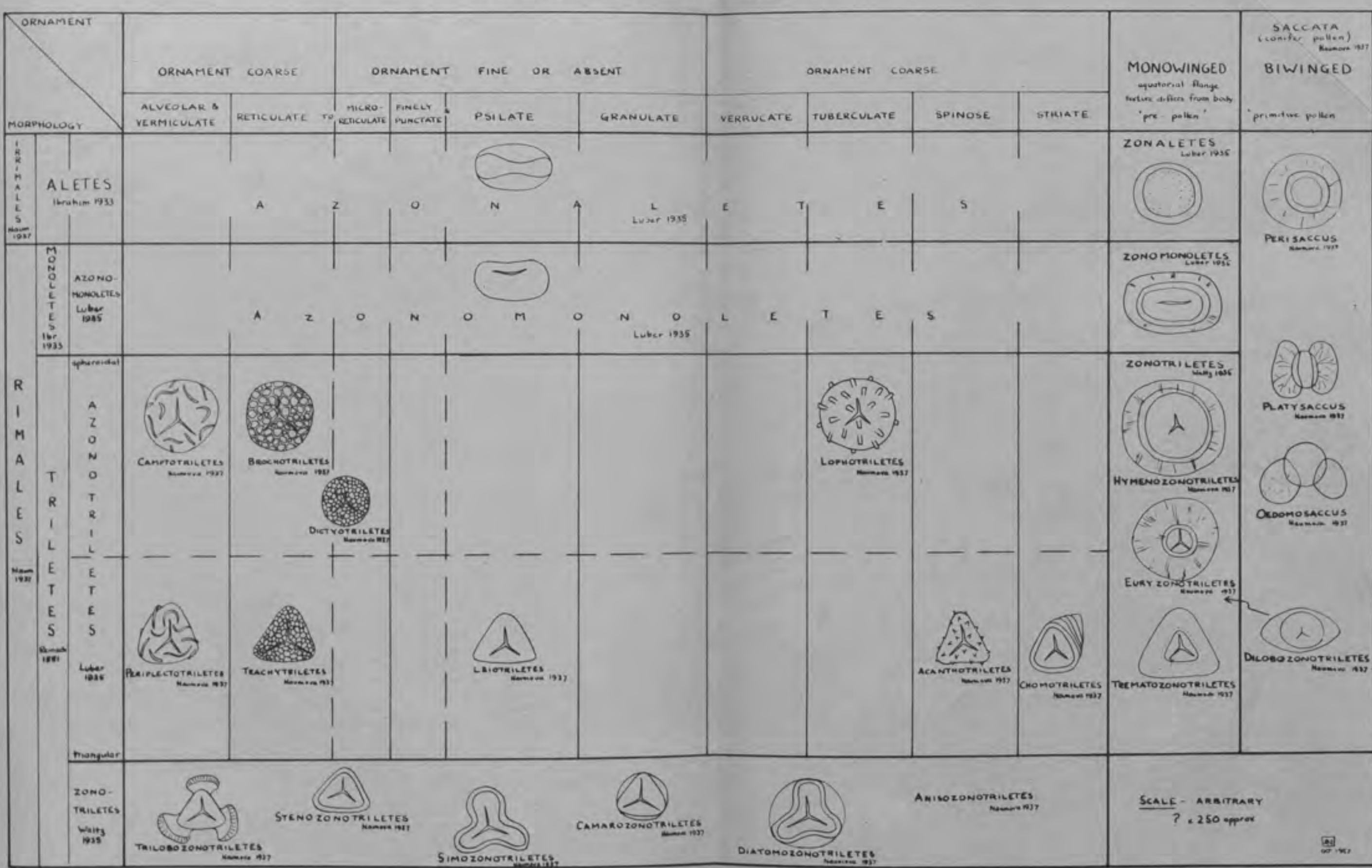


CHART 4

CLASSIFICATION of SPOROMORPHS ~ AUSTRALIA

DULHUNTY 1945, 1949, DE JERSEY 1946, BALME 1952

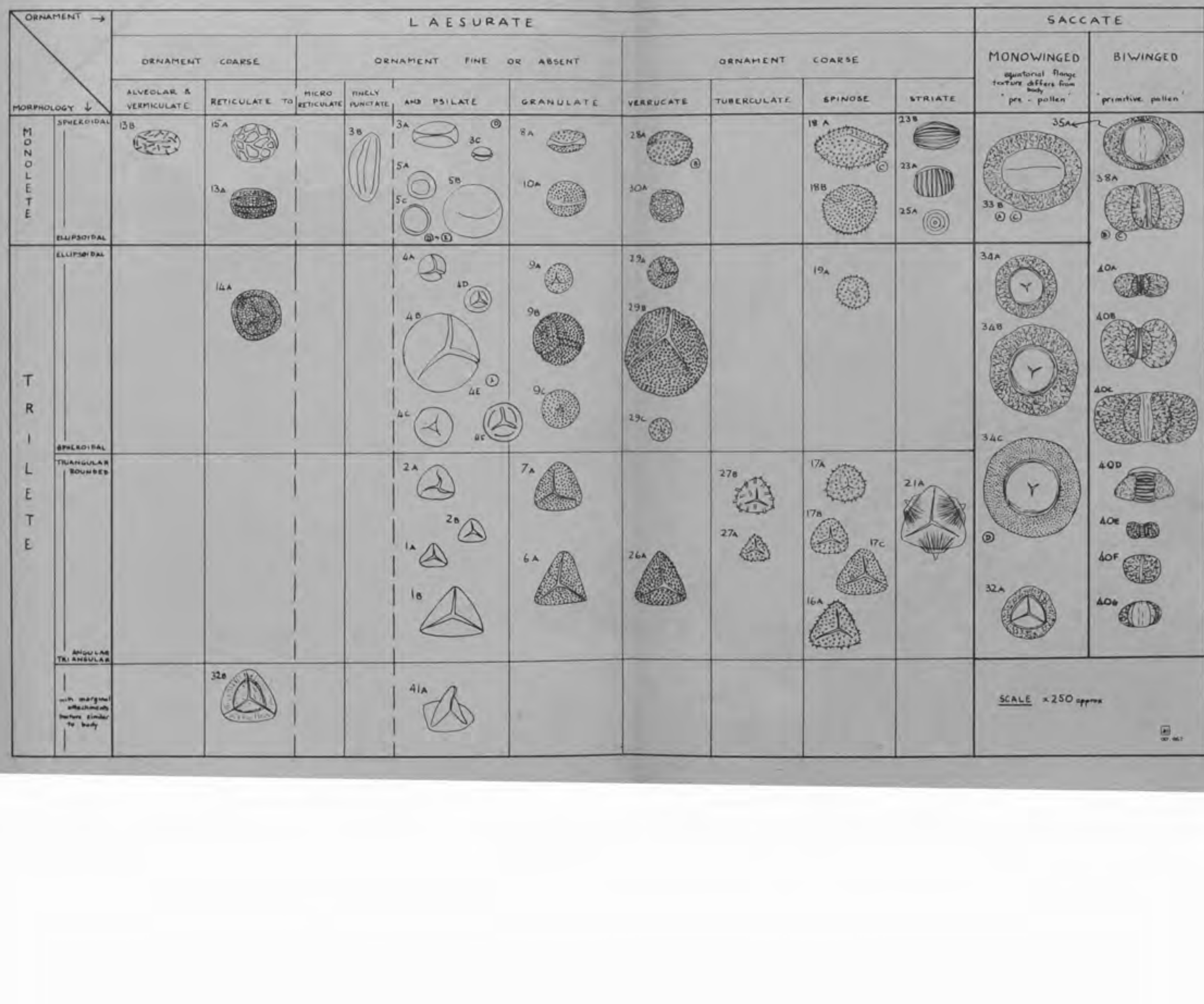


CHART 5

CLASSIFICATION OF SPOROMORPHS ~ INDIA ~ PERMO-TRIAS

1. VIRKKI 1945

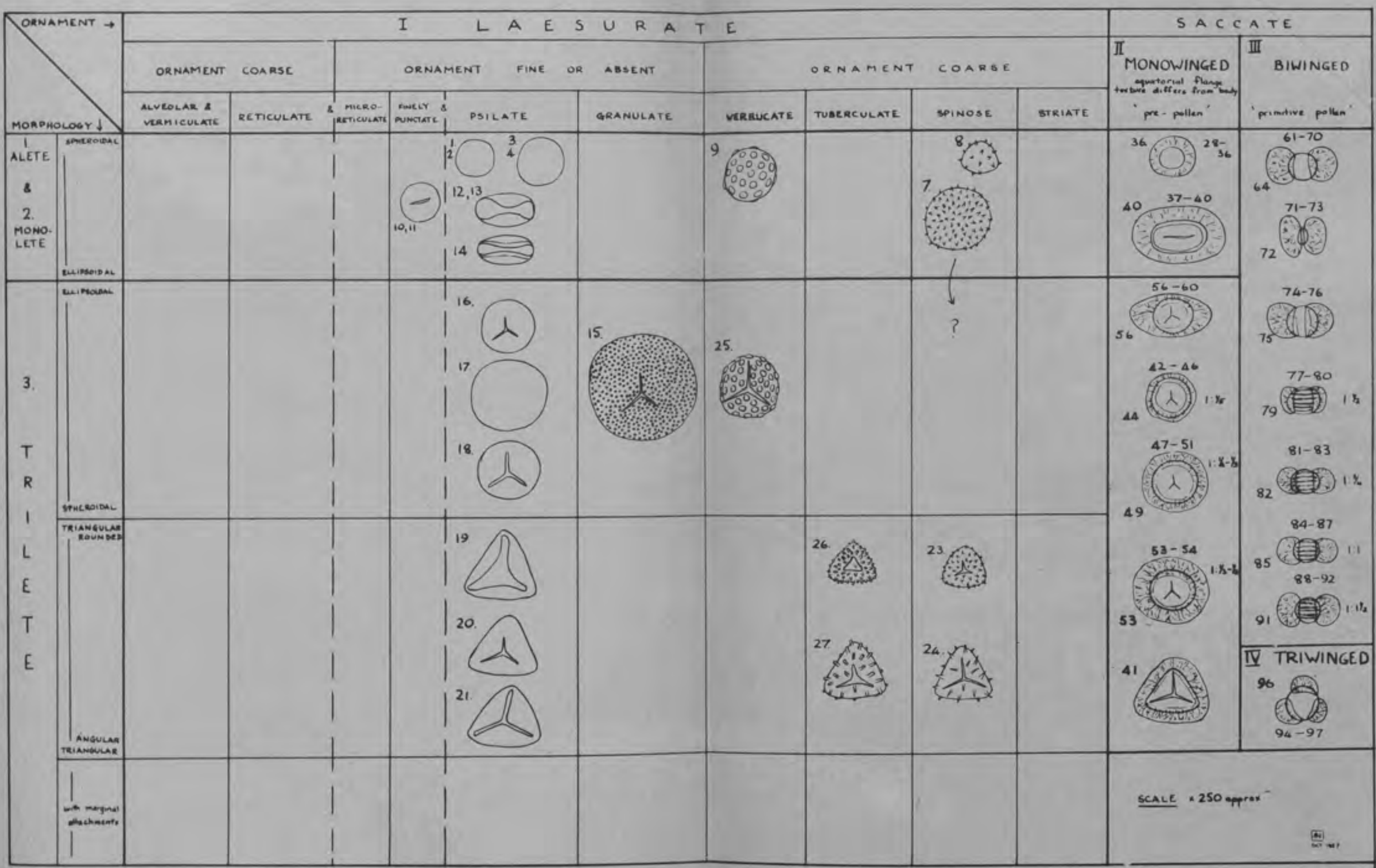
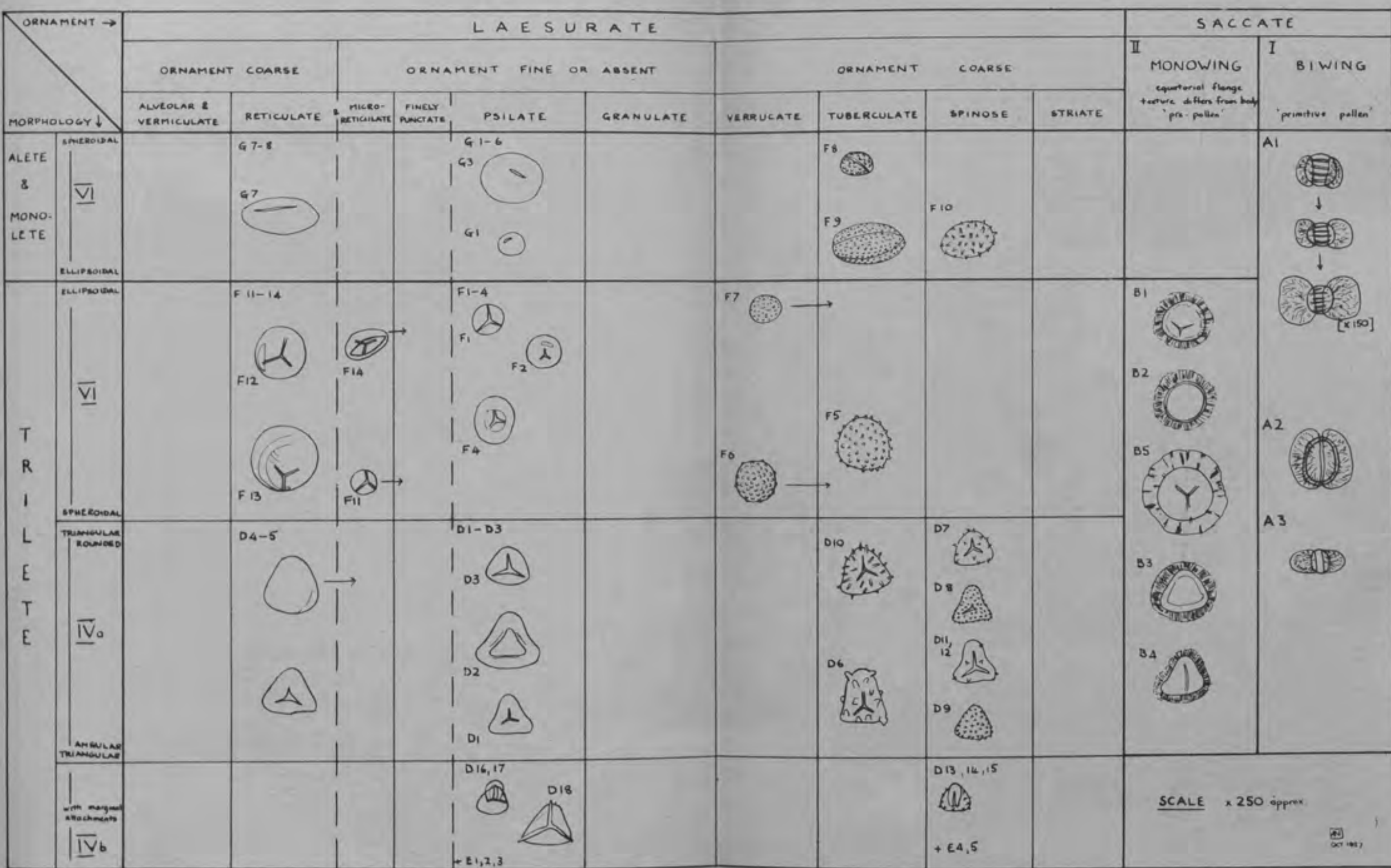


CHART 6

CLASSIFICATION OF SPOROMORPHS - INDIA - PERMO-TRIAS

2. GHOSH & SEN 1948, SEN 1953.



CLASSIFICATION OF SPOROMORPHS - PALÆOZOIC

CHART 7

SCHOPF, WILSON & BENTALL 1944, KOSANKE 1950, KNOX 1950.

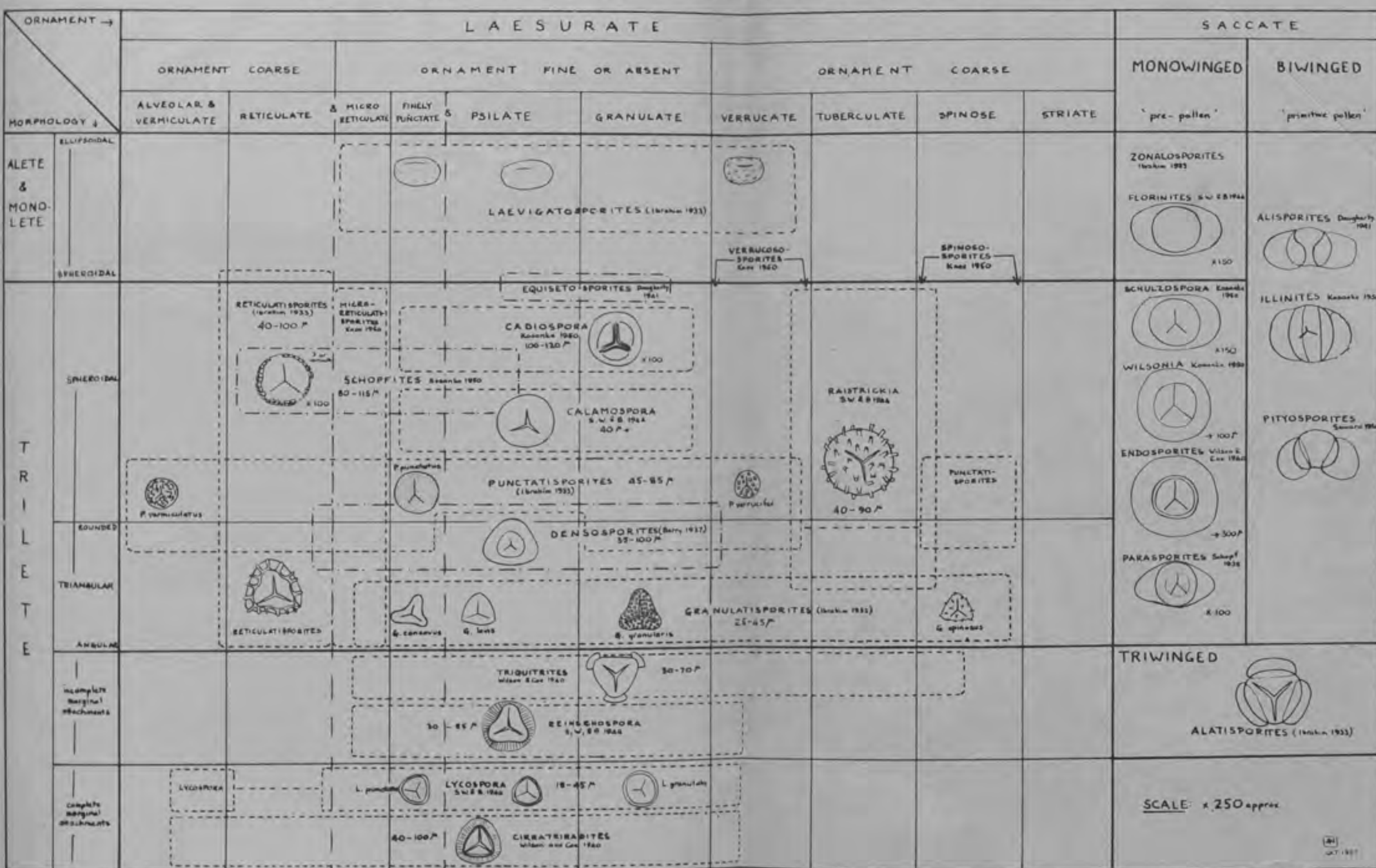
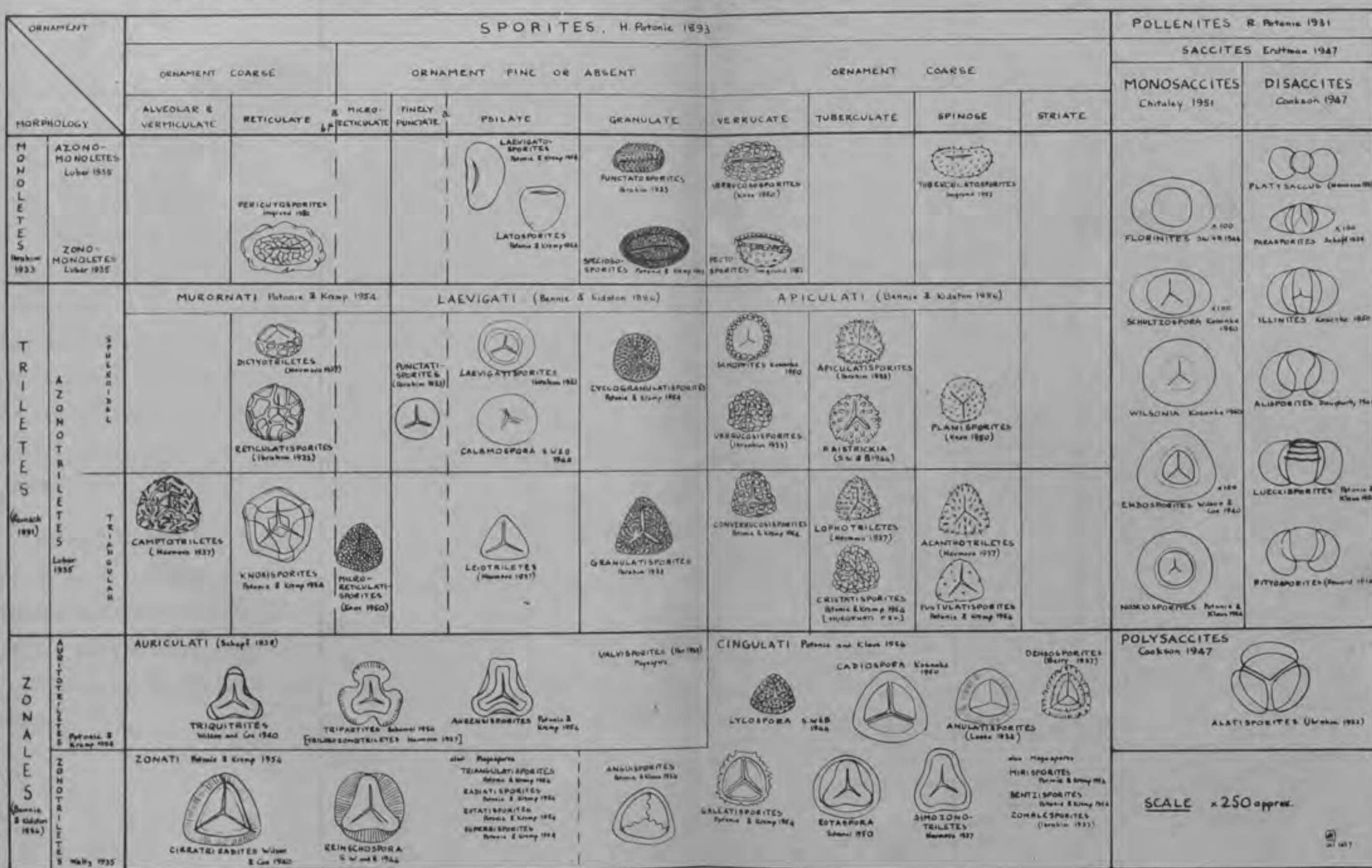


CHART 8

CLASSIFICATION OF SPOROMORPHS - PALÆOZOIC

R. POTONIE & KREMP 1954, POTONIE & KLAUS 1954, [POTONIE & KREMP MONOGRAPH PT 1 1956]



(7) Systematic descriptions of Sporomorphae

Detailed descriptions are given here of all distinct spore types encountered during the study of the Ruhuhu material. Several of the less common types (eg 17b) have been found more abundantly in other samples from Tanganyika, and have been included amongst this group of descriptions although not present in sufficient numbers to have warranted describing otherwise. Thus it may appear that descriptions have been based on relatively few spore specimens when, in actual fact more have been seen than are recorded. The variable preservation of the specimens may affect descriptions, in that only those specimens with almost all dimensions etc. in fact have been measured while those which are incomplete in some way or other have not been measured but will have contributed to the knowledge of the appearance of the spore.

Where possible specimens have been measured from all the horizons at which they occur within the limits of the material including both of the Mchuchuma boreholes. This is to give, as nearly as possible a comprehensive description of the range of a sporomorph in time and space. All measurements are in microns.

The spore descriptions have been made to conform to a specific layout covering all the visible features of each type. No naming or synonymy is included in the descriptions as the author feels that the work is too isolated as yet to justify such a step, and that more work would be necessary in comparative studies of other Permian spores before attempting the naming and comparisons of these specimens. However, a diagrammatic synonymy has been included in the section on classification. (Charts 1-8.)

DESCRIPTION OF SPORE 2a

SUTURE: Monolete

SYMMETRY: Bilateral

SHAPE AND FORM: Oval; suture longitudinal, may have thickened rim.

ORNAMENT: Microreticulate or punctate, ornament less than 2 microns accross.

MICROSCOPIC APPEARANCE: (saffranin stained) not normally well preserved.

SIZE RANGE: 10 specimens

spore body 19-68x13-25

suture 9-50

AVERAGE SIZE: 10 specimens

spore body 46.5 x 27.9

suture 24.75

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
CoalShale	7. . .	19-65 x 13-59	9-50	44.5 x 26.4	22.0
MCHUCHUMA					
Top Seam) Intermediate)	3	36-59 x 28-36	24-42	50.3 x 31.3	33.0
Middle Seam	-	-	-	-	-
Lowaer Seam	-	-	-	-	-

DESCRIPTION OF SPORE 3a

SUTURE: Monolete

SYMMETRY: Bilateral

SHAPE AND FORM: Ellipsoidal, tendency to bean shape, with longitudinal suture normally closed, sometimes open.

ORNAMENT: Absent

MICROSCOPIC APPEARANCE: (saffranin stained) pale pink in colour, nearly transparent.

SIZE RANGE : 10 specimens		AVERAGE SIZE: 10 specimens	
spore body	22-54 x 14-38	spore body	31.1 x 20.9
suture	11-50	suture	21.9

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal shale	7	22-32 x 14-25	11-26	24.3 x18.5	14.5
MCHUCHUMA					
Top Seam) Intermediate Middle Seam)	3	26-54 x 13-38	16-50	40.0-26.3	32.0
Lower Seam	-	-	-	-	-

DESCRIPTION OF SPORE 3b

SUTURE: Monolete

SYMMETRY: Bilateral

SHAPE AND FORM: Ellipsoidal, with open longitudinal suture, may have thickened rims and normally almost length of body.

ORNAMENT: Absent

MICROSCOPIC APPEARANCE: (saffranin stained) pale to dark, almost transparent

SIZE RANGE: 15 specimens		AVERAGE SIZE: 15 specimens	
spore body	16-59 x 9-40	spore body	34.2 x 26.0
suture	14-45	suture	26.2

SIZES AT SPECIFIC HORIZONS:

	N0 of spores	size range: spore body	size range: suture	average size: spore body	average size: suture
MBUKURA					
Coal Shale	7	16-25 x 9-40	15-45	36.0 x 22	29.1
MCHUCHUMA					
Top Seam, Intermediate, Middle Seam, Lower Seam	8	20-59 x 13-39	14-40	32.6 x 19.3	23.6

DESCRIPTION OF SPORE 4a

SUTURE: Monolete

SYMMETRY: Bilateral

SHAPE AND FORM: Ellipsoidal - suture longitudinal, open or closed.

ORNAMENT: Granules about 1 micron diameter, widely spaced.

MICROSCOPIC APPEARANCE: (saffranin stained) pale pink with white spots as it comes into focus, on further lowering of objective, dark granules on light background.

SIZE RANGE: 7 specimens

spore body 18-50 x 11-47

suture 16-48

SIZES AT SPECIFIC HORIZONS:

	No. of spores	Size range Spore body	Size range Suture	Average size Spore body	Average size Suture
MBUYURA					
Coal Shale	4	28-50 x 11-47	19-48	42.7 x 27.7	28.5
MCHUCHUMA					
Top Seam	3	18-27 x 12-14	16-18	22.6 x 13.3	16.6
Intermediate	-	-	-	-	-
Middle Seam	-	-	-	-	-
Lower Seam	-	-	-	-	-

DESCRIPTION OF SPORE 5a

SUTURE: Monolete but obscured

SYMMETRY: Bilateral

SHAPE AND FORM: Ellipsoidal, suture usually obscured by ornament

ORNAMENT: rounded verrucae, or irregular raised areas. 4 - 8 microns long, 2 - 5 microns wide

MICROSCOPIC APPEARANCE: (saffranin stained) when focussed down dark verrucae on light background

SIZE RANGE: 3 specimens

spore body 27-32 x 21-22

suture 20-22

SIZES AT SPECIFIC HORIZONS:

	No of spores	Size range Spore body	Size range Suture	Average size Spore body	Average size Suture
MBUYURA					
Coal Shale					
MCHUCHUMA					
Top Seam	1	30 x 21	22	-	-
Intermediate	-				
Middle Seam	1	27 x 22	?	-	-
Lower Seam	1	32 x 22	20	-	-

DESCRIPTION OF SPORE 6a

SUTURE: Monolete

SYMMETRY: Bilateral

SHAPE AND FORM: Ellipsoidal, suture longitudinal, may be obscured

ORNAMENT: flattened tubercles irregularly arranged, 2-4 microns long, up to 2 microns wide

SIZE RANGE: 5 specimens

spore body 39-74 x 26-50

suture 25-64

SIZES AT SPECIFIC HORIZONS:

	No of spores	Size range Spore body	Size range Suture	Average size Spore body	Average size Suture
MBUYURA					
Coal Shale	4	39-74 x 28-50	29-64	57.2 x 37.7	47.3
MCHUCHUMA					
Top Seam	-	-	-	-	-
Intermediate	-	-	-	-	-
Middle Seam	-	-	-	-	-
Lower Seam	1	40 x 26	25		

DESCRIPTION OF SPORE 7a

SUTURE: Monolete

SYMMETRY: Bilateral

SHAPE AND FORM: Ellipsoidal - elongated to nearly rounded, longitudinal suture, which is generally visible.

ORNAMENT: Spinose: spines < 2 microns broad at base, up to 3 microns long

MICROSCOPIC APPEARANCE: (saffranin stained) Exine and spines both similar density - darkish pink

SIZE RANGE: 27 specimens
spore body 22-41 x 15-26
suture 12-40

AVERAGE SIZE: 27 specimens
Spore body 29.2 x 18.5
suture 18.8

SIZES AT SPECIFIC HORIZONS:

	No of spores	Size range spore body	Size range suture	Average size spore body	Average size suture
MBUYURA					
Coal Shale	14	22-41 x 15-26	12-40	29.4 x 18.2	21.0
MCHUCHUMA					
Top Seam) Intermediate)	13	24-32 x 14-24	13-24	29.0 x 18.8	17.0
Middle Seam	-	-	-	-	-
Lower Seam	-	-	-	-	-

DESCRIPTION OF SPORE 7b

SUTURE: Monolete

SYMMETRY: Bilateral

SHAPE AND FORM: Ellipsoidal - suture not always visible due to coarse ornament.

ORNAMENT: Heavy spines generally > 2 microns in width at base 2-4 microns long; may have almost verrucate base with spine above (as seen in side view).

MICROSCOPIC APPEARANCE: (saffranin stained) Exine and spines similar density - generally darkish pink

SIZE RANGE: 17 specimens
spore body 25-41 x 11-24
suture 16-30

AVERAGE SIZE: 17 specimens
spore body 31.3 x 18.3
suture 21.5

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	11	25-41 x 11-23	16-30	31.5 x 18.1	21.8
MCHUCHUMA					
Top Seam) Intermediate)	6				
Middle Seam					
Lower Seam	-	-	-	-	-

DESCRIPTION OF SPORE 8a (PLATES 1-2)

SUTURE: ? Monolete

SYMMETRY: Bilateral

SHAPE AND FORM: Ellipsoidal - suture never seen, occasionally a small margin is visible around part of the edge.

ORNAMENT: Striate - striae generally 1-2 microns wide, 1 micron apart, smaller in Mchuchuma specimens than Mbuyura.

MICROSCOPIC APPEARANCE: (saffranin stained) dark granular striae with pale stripe between.

SIZE RANGE: 30 specimens
spore body 42-120 x 22-84
suture

AVERAGE SIZE: 30 specimens
spore body 71.5 x 45.6
suture

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	17	42-97 x 22-50	-	66.0 x 41.1	-
MCHUCHUMA					
Top Seam) Intermediate)	13	54-120 x 36-84	-	78.6 x 51.4	-
Middle Seam	-	-	-	-	-
Lower Seam	-	-	-	-	-

DESCRIPTION OF SPORE 12a

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Discoidal but may be elongated, suture may be relatively short or long - not usually more than 1/8 diameter

ORNAMENT: microreticulate to obervermiculate - irregular, usually > 1 micron

MICROSCOPIC APPEARANCE: (saffranin stained) 'reticulations' dark in colour and irregularly arranged.

SIZE RANGE: 30 specimens — AVERAGE SIZE: 30 specimens

	SIZE RANGE: 30 specimens	AVERAGE SIZE: 30 specimens
spore body	30-74	49.6
suture	4-32	21.0

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	11	30-70 diam	4-21	42.8	10.2
MCHUCHUMA					
Top Seam	8	34-74	13-20	51.8	15.6
Intermediate	7	40-74	7-22	52.3	11.0
Middle Seam	4	38-72	7-32	59.5	22.7
Lower Seam	-	-	-	-	-

DESCRIPTION OF SPORE 12b

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Discoidal - normally small in size about 35 microns, but occasional larger forms; regular outline; light in colour.

ORNAMENT: Microreticulate - sometimes faint, but always regular meshwork; generally less than 1 micron across.

MICROSCOPIC APPEARANCE: (saffranin stained) light pink in colour, with reticulation visible when objective focussed up and down, - light when first in view; then darker when focussing down.

SIZE RANGE: 22 specimens		AVERAGE SIZE: 22 specimens	
spore body	29-60	spore body	36.8
suture	4-25	suture	11.4

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	8	30-50	5-25	36.8	14.1
MCHUCHUMA					
Top Seam) Intermediate) Middle Seam) Lower Seam)	14	29-60	4-16	36.8	10.1

DESCRIPTION OF SPORE 13a

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Triangular, regular, straight sided, rounded apices.

ORNAMENT: Irregular reticulate, 1-3 microns across.

MICROSCOPIC APPEARANCE: (saffranin stained) well stained irregular markings; dark reticular appearance.

SIZE RANGE: 17 specimens		AVERAGE SIZE: 17 specimens	
spore body	25-47	spore body	36.6
suture	4-16	suture	10.75

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	10	25-47	5-14	34.3	10.6
MCHUCHUMA					
Top Seam) Intermediate) Middle Seam) Lower Seam)	7	37-47	4-16	40.0	11.0

DESCRIPTION OF SPORE 13b

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Triangular, regular, rounded apices, straight to convex sides.

ORNAMENT: Regular, microreticulate (and punctate) less than 1½ microns

MICROSCOPIC APPEARANCE: (saffranin stained) pale stained, reticulations white when first in focus - suture may be petalloid.

SIZE RANGE: 71 specimens		AVERAGE SIZE: 71 specimens	
spore body	28-50	spore body	38.0
suture	5-28	suture	15.6

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	24	28-60	5-28	38.0	14.7
MCHUCHUMA					
Top Seam	15	31-42	10-23	34.5	15.2
Intermediate	11	29-40	13-18	34.5	15.4
Middle Seam	4	28-47	8-19	39.2	15.5
Lower Seam	17	33-47	9-24	40.2	16.2

DESCRIPTION OF SPORE 13c

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Triangular, flattened, having central body, and outer skin giving impression of complete but thin equatorial margin. Suture present in outer layer not in darker central body. Suture may have thickened ridge.

ORNAMENT: microreticulate, but variable in size of reticulations - usually fine.

MICROSCOPIC APPEARANCE: (saffranin stained) faint staining, with reticulations appearing as faint white meshwork. Central portion always more dense than outer layer, and often less well marked.

SIZE RANGE: 19 specimens

spore body 38-69 (26-57)

suture 14-30

AVERAGE SIZE: 18 specimens

spore body 52.9 (37.0)

suture 21.1

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	7	40-69 (30-57)	20-27	57.1 (44.8)	23.3
MCHUCHUMA					
Top Seam	8	38-57 diam (26-38)	14-30/^{u}	50.1 (31.2)	18.0
Intermediate	3	46-54 (29-38)	22-28	50.6 (34.3)	24.3
Middle Seam	-	-	-	- -	-
Lower Seam	-	-	-	- -	-

DESCRIPTION OF SPORE 14a (PLATE 3)

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Discoidal, circular regular, suture small to medium.

ORNAMENT: absent.

MICROSCOPIC APPEARANCE: (saffranin stained) smooth, pale stained.

SIZE RANGE: 83 specimens
spore body 12-35
suture 3-15

AVERAGE SIZE: 83 specimens
spore body 23.3
suture 4.9

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	34	14-34	3-13	23.9	5.8
MCHUCHUMA					
Top Seam	19	14-30	3-13	23.9	7.2
Intermediate	5	14-21	3-6	18.6	3.8
Middle Seam	6	19-30	3-9	24.2	5.8
Lower Seam	2	22-28	7	26.0	7.0
Thick Seam	17	12-35	3-10	23.0	5.8

DESCRIPTION OF SPORE 14b (PLATE 4)

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Discoidal, regular, large: suture usually extends to margin in range 50-90 microns.

ORNAMENT: absent

MICROSCOPIC APPEARANCE: (saffranin stained) pale to dark in colour, not dense, smooth appearance.

SIZE RANGE: 81 specimens		AVERAGE SIZE: 81 specimens	
spore body	49-94	spore body	73.9
suture	10-36	suture	23.0

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	25	49-90	10-36	75.5	22.7
MCHUCHUMA					
Top Seam	12	54-94	16-32	75.8	25.8
Intermediate	9	49-86	18-29	60.3	23.6
Middle Seam	11	64-82	13-29	70.9	23.0
Lower Seam	12	54-82	13-35	68.1	23.2
Thick Seam	12	61-86	15-33	70.9	20.9

DESCRIPTION OF SPORE 14c (PLATE 5)

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Discoidal, medium size suture normally small.

ORNAMENT: absent, but may be dense giving appearance of punctate.

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 37 specimens — AVERAGE SIZE: 37 specimens

	SIZE RANGE	AVERAGE SIZE
spore body	30-54	40.3
suture	4-17	8.9

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	14	30-54	5-17	41.3	8.6
MCHUCHUMA					
Top Seam	4	31-38	7-13	37.7	10.0
Intermediate	6	32-49	6-15	42.5	10.5
Middle Seam)) Lower Seam)	13	31-49	4-13	39.0	8.1

DESCRIPTION OF SPORE 15a

SUTURE: Trilete

SYMMETRY: Radial

SHAPE and FORM: Triangular regular, straight sides rounded apices.

ORNAMENT: absent although may have very fine ornament.

MICROSCOPIC APPEARANCE: (saffranin stained) pale, almost transparent, remains smooth on careful focussing.

SIZE RANGE: 62 specimens		AVERAGE SIZE: 62 specimens	
spore body	22-48	spore body	34.4
suture	5-24	suture	14.5

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	30	22-48	7-22	32.5	13.4
MCHUCHUMA					
Top Seam	8	30-39	11-21	34.6	15.2
Intermediate	6	32-40	5-17	35.8	12.2
Middle Seam	6	34-41	13-22	37.3	16.7
Lower Seam	7	31-44	14-24	39.0	18.3
Thick Seam	5	32-38	13-18	32.0	14.6

DESCRIPTION OF SPORE 16a

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Discoidal, small; with short suture.

ORNAMENT: scattered, discreet granules, each approx. 1-1½ microns diameter.

MICROSCOPIC APPEARANCE: (saffranin stained) when first in focus, granules appear as white spots on dark ground; when exine in focus reverse is true.

SIZE RANGE: 61 specimens		AVERAGE SIZE: 61 specimens	
spore body	14-32	spore body	22.6
suture	3-18	suture	7.0

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	25	16-30	3-12	22.5	7.1
MCHUCHUMA					
Top Seam	11	16-23	4-8	19.7	6.3
Intermediate	8	19-23	3-7	20.6	5.9
Middle Seam	4	22-32	6-14	26.0	8.4
Lower Seam	6	22-30	3-11	25.3	7.2
Thick Seam	7	14-28	4-18	22.4	7.6

DESCRIPTION OF SPORE 17a

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Triangular - rounded convex sides, apices tending to be pointed; generally small, with small suture (triangular f~~an~~orm of 16a)

ORNAMENT: scattered discreet granules from 1-2 microns diameter.

MICROSCOPIC APPEARANCE: (saffranin stained) when granules in focus, white spots on dark ground, when exine in focus, dark spots in light ground.

SIZE RANGE: 11 specimens		AVERAGE SIZE: 11 specimens	
spore body	17-28	spore body	20.6
suture	3-15	suture	7.2

SIZES AT SPECIFIC HORIZONS:

	No of spores	Size range spore body	Size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	7	17-28	4-15	21.3	8.1
MCHUCHUMA					
Top Seam) Intermediate) Middle Seam) Lower Seam)	4	18-22	3-8	19.5	5.5

DESCRIPTION OF SPORE 17b

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Medium size, triangular with slightly convex sides and rounded apices. Suture is long, tendency to be petalloid.

ORNAMENT: Discreet granules 1-1½ microns diameter, closely and regularly packed.

MICROSCOPIC APPEARANCE: (saffranin stained) when granules in focus, white spots on a darkish surface.

SIZE RANGE: 1 specimen

Spore body 41

Suture 18

This spore may have been included in 13b in early stages of investigation as at least one is recorded from the Top Seam of Mchuchuma. (More have been observed but not well enough preserved for measuring. Actually, relatively abundant in Kivira Songwe coals - younger?)

DESCRIPTION OF SPORE 18a

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Medium size, with large scattered vernicae, of rounded regular form - discoidal, suture obscure, but position visible between verrucae.

ORNAMENT: regular (globular) verrucae. 2-4 microns diameter (ie large granules).

MICROSCOPIC APPEARANCE: (saffranin stained)
when vernicae in focus white, circular patches on darker ground. Those at edges give semicircular section.

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	-	-	-	-	-
MCHUCHUMA	-	-	-	-	-
Top Seam	-	-	-	-	-
Intermediate	-	-	-	-	-
Middle Seam) Lower Seam)	2	44 and 52	? 3-4		

Not usually well enough preserved for measurement

DESCRIPTION OF SPORE 18b (PLATE 7)

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Discoidal, having irregularly shaped (oblong to oval) raised patches. Suture variable; size medium.

ORNAMENT: irregular raised patches, about 2 microns wide and up to 7 microns long, 1½ high.

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 6 specimens

spore body 33-58

suture 5-18

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	3	47-58	5-18	53.0	11.5
MCHUCHUMA					
Top Seam / Intermediate / Middle Seam	3	33 -43	5-9	37.0	7.0
Lower Seam	-	-	-	-	-

DESCRIPTION OF SPORE 19a and b

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Triangular, convex sides and rounded apices. Suture indicated by break in ornament, often obscured; size variable, probably includes triangular forms of both 18a and 18b.

ORNAMENT: mainly irregular large raised patches (vernicae) 2 microns wide, up to 2 microns high, and up to 6 microns long.

MICROSCOPIC APPEARANCE: (saffranin stained) large white patches on a dark ground.

SIZE RANGE: 8 specimens

spore body 24-64

suture 5-18

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	3	30-64	12-15	44.0	9.0
MCHUCHUMA					
Top Seam / Intermediate / Middle Seam	5	24-42	5-18	32.0	11.0
Lower Seam	-	-	-	-	-

DESCRIPTION OF SPORE 20a

SUTURE: Trilete
SYMMETRY: Radial
SHAPE AND FORM: Discoidal

ORNAMENT: short, discreet tubercles approximately 1 micron in width, 2-4 microns long.

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 15 specimens		AVERAGE SIZE: 15 specimens	
spore body	39-60	spore body	45.4
suture	6-16	suture	10.0

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	13	39-52	6-16	44.5	10.2
MCHUCHUMA	(abundant at MB/3 level)				
Top Seam, Intermediate, Middle Seam, Lower Seam	2	43-60	7	51.5	7.0

DESCRIPTION OF SPORE 20b

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Discoidal plus projections.

ORNAMENT: short or long compound tubercles - cristate (coalescent form) up to 8 microns long and 3 microns wide

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 23 specimens
spore body 28-60
suture 6-20

AVERAGE SIZE: 23 specimens
spore body 49.3
suture 12.5

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	5	28-57	6-12	40.6	9.4
MCHUCHUMA					
Top Seam / Intermediate	5	30-57	8-18	45.4	12.2
Middle Seam / Lower Seam	13	47-60	9-20	54.1	14.0

DESCRIPTION OF SPORE 21a

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Triangular form of 20a

rounded triangular

ORNAMENT: simple tubercles

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 6 specimens

spore body 31-70

suture 15

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range: spore body	size range: suture	average size: spore body	average size: suture
MBUYURA					
Coal Shale	2	44-70	?	57.0	?
MCHUCHUMA					
Top Seam) Intermediate) Middle Seam)	4	31-41	15	38.0	15
Lower Seam	-	-	-	-	-

DESCRIPTION OF SPORE 21b

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Triangular form of 20b
rounded triangular

ORNAMENT: compound tubercles

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 9 specimens
spore body 35-52
suture 12-22

AVERAGE SIZE: 9 specimens
spore body 43.7
suture 17.0

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	3	35-46	19	42.0	19
MCHUCHUMA					
Top Seam, Intermediate, Middle Seam, Lower Seam	6	35-52	12-22	44.5	16.6

DESCRIPTION OF SPORE 21c (PLATE 8)

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Triangular medium size straight sides, well rounded apices; suture usually well formed, maybe open.

ORNAMENT: fairly large flattened tubercles, blunt ended. 2-6 microns in length, 1-2 broad, spaced up to 4 microns apart.

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 14 specimens)

spore body 23-58

suture 3-19

AVERAGE SIZE: 14 specimens

spore body 37.0

suture 12.7

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	9	23-38	3-18	31.5	11.5
MCHUCHUMA					
Top Seam) Intermediate) Middle Seam) Lower Seam)	5	32-58	7-19	46.5	14.8

DESCRIPTION OF SPORE 22a

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Small, discoidal

ORNAMENT: spines - conical projections 1-3 microns in length, 1-2 microns base diameter.

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 52 specimens

spore body 19-30

suture 2-13

AVERAGE SIZE: 52 specimens

spore body 24.4

suture 6.5

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	30	19-30	2-11	24.4	6.0
MCHUCHUMA					
Top Seam	11	19-27	8-9	24.7	8.5
Intermediate	7	23-27	5-13	25.0	7.6
Middle Seam	4	20-26	6	22.7	6
Lower Seam	absent		-	-	-

DESCRIPTION OF SPORE 22b

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Discoidal small, to medium

ORNAMENT: Spinose - broad bases to rather blunt spines greater than 2 microns diameter, and 2-4 microns long.

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 27 specimens

spore body	21-41
suture	4-18

AVERAGE SIZE: 27 specimens

spore body	31.6
suture	9.5

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	17	26-41	4-15	31.7	7.9
MCHUCHUMA					
Top Seam	3	25-40	8-13	32.3	10.5
Intermediate	3	21-38	11-17	27.3	14.0
Middle Seam	4	31-37	11-18	33.5	14.5
Lower Seam	-	absent	-	-	-

DESCRIPTION OF SPORE 22c

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Discoidal small to medium

ORNAMENT: spinose, small conical spines, less than 1 micron at base, less than 2 microns in length (side view triangular)

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 12 specimens

spore body	19-33
suture	4-16

AVERAGE SIZE: 12 specimens

spore body	24.4
suture	6.0

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	8	19-33	4-9	23.9	5.7
MCHUCHUMA					
Top Seam	6	22-29	4-16	25.2	6.3
Intermediate	-	-	-	-	-
Middle Seam	-	-	-	-	-
Lower Seam	-	=	-	-	-

DESCRIPTION OF SPORE 23a

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Triangular - rounded triangular convex sides and angular apices (triangular form of 22a) small

ORNAMENT: spinose - conical spines 1-3 microns in length, 1-2 microns at base

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 33 specimens

spore body 19-38

suture 4-14

AVERAGE SIZE: 33 specimens

spore body 26.2

suture 8.8

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	18	19-38	4-14	27.6	9.1
MCHUCHUMA					
Top Seam	11	22-27	6.13	23.8	8.6
Intermediate)) Middle Seam)	4	23-27	8 & 9	25.2	8.5
Lower Seam	-	-	-	-	-

DESCRIPTION OF SPORE 23b

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Triangular, convex sides, angular apices (triangular form of 22b)

ORNAMENT: spinose - spines having broad bases, > 2 microns, 2-4 microns long

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 20 specimens
spore body 23-41
suture 5-17

AVERAGE SIZE: 20 specimens
spore body 31.3
suture 11.1

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	15	24-41	5-17	32.5	11.0
MCHUCHUMA					
Top Seam, Intermediate, Middle Seam	5	23-37	7-15	27.8	11.5
Lower Seam	-	-	-	-	-

DESCRIPTION OF SPORE 23c

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Triangular - small to medium, convex sides, rounded apices (triangular form of 22c)

ORNAMENT: spinose -small conical spines, $<$ 2microns in length $<$ 1 micron at base

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 20 specimens		AVERAGE SIZE: 20 specimens	
spore body	17-35	spore body	26.5
suture	4-15	suture	9.5

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	8	17-35	4-13	24.1	5.8
MCHUCHUMA					
Top Seam	8	21-35	9-15	28.7	12.5
Intermediate) Middle Seam)	4	27-32	6-13	29.5	8.7
Lower Seam	-	-	-	-	-

DESCRIPTION OF SPORE 23d

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Triangular - concave sides, rounded apices small to medium

ORNAMENT: spinose - conical spines, > 2 microns at base, > 2 microns in length (up to 6 microns), usually 2-4 microns apart

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 19 specimens		AVERAGE SIZE: 19 specimens	
spore body	16-38	spore body	27.4
suture	6-16	suture	11.4

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	15	16-38	6-16	27.2	11.4
MCHUCHUMA					
Top Seam, Intermediate, Middle Seam	4	25-32	11-12	28.2	11.5
Lower Seam	-	-	-	-	-

DESCRIPTION OF SPORE 31a

SUTURE: Monolete

SYMMETRY: Bilateral

SHAPE AND FORM: Ovoid spore body, having an equatorial flange or wing, of equal radial dimensions; - suture longitudinal

ORNAMENT: Spore body microreticulate to smooth. Wing more coarsely microreticulate, with tendency to alignment of ornament

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 10 specimens		AVERAGE SIZE: 10 specimens	
spore body	51-85x38-65	spore body	70.4x49.5
suture	? only one 20	suture	-
Appendages	10-20	Appendages	13 broad

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	10	as above			
MCHUCHUMA					
Top Seam	none measured, few recorded				
Intermediate					
Middle Seam					
Lower Seam					

DESCRIPTION OF SPORE 32a (PLATE 9)

SUTURE: Trilete when visible

SYMMETRY: Radial

SHAPE AND FORM: Discoidal body having equatorial flange or wing narrow in comparison to body ($< \frac{1}{3}$ diameter) of equal radial dimensions, wing in form of overlapping sac in complete unflattened specimens - up to 20 microns overlap

ORNAMENT: microreticulate body, wing generally more coarsely reticulate with tendency to veination

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 29 specimens		AVERAGE SIZE: 29 specimens	
spore body	45-90	spore body	61.2
suture	3-20	suture	c 10.1
appendages	6-22	appendages	c 13.0

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	22	45-85 wings 6-22	3-20	58.4 wings 12.5	8.4
MCHUCHUMA					
Top Seam, Intermediate, Middle Seam, Lower Seam	7	55-90 wings 10-20	4-20	70.3 wings 15	14.1

DESCRIPTION OF SPORE 32b

SUTURE: Trilete

SYMMETRY: Radial

SHAPE AND FORM: Discoidal spore body, having equatorial wing or sac, broad in comparison to diameter i e ⅓ or greater; overlap up to 17 microns

ORNAMENT: microreticulate body, wing coarser, tendency to veination

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 28 specimens		AVERAGE SIZE: 28 specimens	
spore body	35-80 + wing	spore body	c 53.9 (+ wing 89.9)
suture	5-16	suture	c 9.0
appendages	11-30	appendages	c 18.0

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	suture	appends	average size spore body	suture	app
MBUYURA							
Coal Shale	24	40-80	5-16	11-30	55.1 (+ wing 91.4) wing c 18	8.6	
MCHUCHUMA							
Top Seam, Intermediate, Middle Seam, Lower Seam	4	35-60	7-15	12-20	48.0 (+ wing 81.2) wing c 16	c 10.2	

DESCRIPTION OF SPORE 32c (PLATES 10-11)

SUTURE: Trilete

SYMMETRY: Bilateral superficially

SHAPE AND FORM: Discoidal spore body, having ellipsoidal equatorial wing or sac; - overlap small

ORNAMENT: body finely microreticulate, wing coarser and veined

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 19 specimens		AVERAGE SIZE: 19 specimens	
spore body	30-73	spore body	54.5
suture	5-12	suture	7.7
appendages	(Max 14-34 (Min 2-12	appendages	(Max 24.4 (Min 5.8

SIZES AT SPECIFIC HORIZONS:

	No of spores	size range spore body	size range suture	average size spore body	average size suture
MBUYURA					
Coal Shale	17	30-73	5-12	55.4	7.7
		wing max 14-34 min 2-12		wing max 24.2 min 6.0	
MCHUCHUMA					
Top Seam) Intermediate) Middle Seam) Lower Seam)	2	48 50 wing max 25-27 min 2-6	- -		

DESCRIPTION OF SPORE 41a (PLATE 14)

SUTURE: ?

SYMMETRY: Bilateral

SHAPE AND FORM: Discoidal to oval body, having 2 lateral air sacs, wing height generally less than body height

ORNAMENT: microreticulate wing ornament, body may be devoid of ornament

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 21 specimens

spore body	(Height	30-58
	(Breadth	20-58
appendages	(Height	
	(Breadth	

AVERAGE SIZE: 21 specimens

spore body	(Height	42.0
	(Breadth	35.3
appendages	(Height	37.1
	(Breadth	26.5

SIZES AT SPECIFIC HORIZONS:

	No of spores		size range spore body	size range wing	average size spore body	average size wing
MBUYURA						
Coal Shale	15	Height	30-58	28-51	41.5	38.0
		Breadth	20-58	14-50	34.5	27.4
MCHUCHUMA						
Top Seam) Intermediate) Middle Seam) Lower Seam)	6	Height	34-54	26-48	43.2	35.7
		Breadth	25-45	12-34	37.3	25.1

DESCRIPTION OF SPORE 41b (PLATES 12-13)

SUTURE: ?

SYMMETRY: Bilateral

SHAPE AND FORM: Oval to discoidal spore body, having 2 lateral air sacs of approximately similar height to body, or slightly greater

ORNAMENT: microreticulate, wings have tendency to veination

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 14 specimens			AVERAGE SIZE: 14 specimens		
spore body	(Height	40-61	spore body	(Height	44.5
	(Breadth	40-61		(Breadth	38.6
appendages	(Height	40-66	appendages	(Height	46.2
	(Breadth	14-49		(Breadth	23.9

SIZES AT SPECIFIC HORIZONS:

	No of spores		size range spore body	wing	average size spore body	wing
MBUYURA						
Coal Shale	11	Height	40-61	40-65	42.2	43.8
		Breadth	40-61	14-49	36.4	22.0
MCHUCHUMA						
	+ 2 large		92 x 61 85 x 68	92 x 20 85 x 37		
Top Seam)						
Intermediate)		Height	50-61	48-66	54.3	56.6
Middle Seam)	3	Breadth	40-57	22-42	38.0	32.3
Lower Seam)						
	+ 1 large		95 x 78	96 x 62		

DESCRIPTION OF SPORE 41c (PLATE 15)

SUTURE: ?

SYMMETRY: Bilateral

SHAPE AND FORM: Smallish oval spore body having 2 distinct lateral air sacs, of distinctly greater height than spore body

ORNAMENT: body microreticulate, wings coarse reticulation, usually veined

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 17 specimens

spore body	(Height	22-70
	(Breadth	28-58, + 1 at 80
appendages	(Height	31-78
	(Breadth	21-52

AVERAGE SIZE: 17 specimens

spore body	(Height	47.2
	(Breadth	38.6
appendages	(Height	58.5
	(Breadth	32.9

SIZES AT SPECIFIC HORIZONS:

	No of spores		size range spore body	size range wings	average size spore body	average size wings
MBUYURA						
Coal Shale	14	Height	22-70	31-78	48.4	58.5
		Breadth	28-58	21-44	43.5	31.3
MCHUCHUMA						
Top Seam) Intermediate) Middle Seam) Lower Seam)	3	Height	35-54	44-77	45.0	59.0
		Breadth	28-80	28-52	49.0	40.6

DESCRIPTION OF SPORE 42a

SUTURE:

SYMMETRY: Radial

SHAPE AND FORM: Oval to discoidal spore body which has 2 bilateral air sacs so placed that almost all the body is obscured and loses obvious saccate form

ORNAMENT: microreticulate, with tendency to veination on sacs

MICROSCOPIC APPEARANCE: (saffranin stained)

SIZE RANGE: 19 specimens			AVERAGE SIZE: 19 specimens		
spore body	(Height		spore body	(Height	47.3
	(Breadth			(Breadth	42.1
appendages	(Height		appendages	(Height	50.0
	(Breadth			(Breadth	32.0

SIZES AT SPECIFIC HORIZONS:

	No of spores		size range spore body	size range wings	average size spore body	average size wings
MBUYURA						
Coal Shale	13	Height	34-68	38-78	46.4	50.1
		Breadth	26-60	17-42	41.7	30.7
MCHUCHUMA						
Top Seam, Intermediate, Middle Seam	6	Height	41-64	42-62	49.3	49.8
		Breadth	28-62	24-52	43.0	36.8
Lower Seam	-	-	-	-	-	-

DESCRIPTION OF SPORE 42b (PLATE 16)

SUTURE:

SYMMETRY: Radial

SHAPE AND FORM: Oval to discoidal spore body, having two lateral air sacs which may or may not completely envelope body - when distinct usually inclined

ORNAMENT: microreticulate, with sacs more coarsely ornamented a varying number of transverse striae appear to correct wing bases - of granular form

SIZE RANGE: 16 specimens			AVERAGE SIZE: 16 specimens		
spore body	(Height	18-40	spore body	(Height	27.2
	(Width	21-36		(Width	25.6
appendages	(Height	21-44	appendages	(Height	30.5
	(Width	18-28		(Width	22.0

SIZES AT SPECIFIC HORIZONS:

	No of spores		size range spore body	wings	average size spore body	wings
MBUYURA						
Coal Shale	4	Height	21.40	26-44	28.7	34.7
		Width	22-36	19-28	26.7	23.7
MCHUCHUMA						
	(1 larger		51 x 48	51 x 21)		
Top Seam) Intermediate) Middle Seam)	13	Height	18-37	21-42	26.9	29.7
		Width	21-33	18-26	24.6	21.7
Lower Seam	-		-	-	-	-

(8) The Constituents of the Ruhuhu Flora

The flora present in the Ruhuhu coalfields is of Upper Ecca age, that is, at the top of the equivalent of the Lower Permian of Europe, namely the top of the Lower Gondwana System of Africa. The similar beds in India are probably the Barakar Coal Measures in Bengal (of Damuda Age) and in Australia, the Lower Coal Measures (or Greta Measures) of New South Wales - the former dealt with by SEN 1953 and the latter by DULHUNTY 1945 and 1946.

A fairly rich flora is indicated by the presence of 45 distinct sporomorphs in this preliminary work. Dulhunty showed 48 for both the Upper and Lower Coal Measures, Sen 28 from the Barakar Measures while Rillett could only identify 12 distinct forms from the Natal coals. In actual fact this is not a rich flora when compared with the 75 genera of micro- and mega-spores with their numerous species, listed by Potonie and Kremp for the Northern hemisphere.

In general the East African spores are small in size. Initial crushing was taken to about 250 μ, but practically all forms were found to be less than half this size. Most forms encountered were less than 50 μ in diameter, and accompanying this smallness of size is a fineness of ornament. The Southern floras are of essentially the same type and form, while the Northern forms tend to be larger and more coarsely ornamented. The Ruhuhu forms show a variety of ornamentation type but always composed of simple elements as opposed to compound or combined sculptural elements, which may be met with in the Northern flora.

The majority of the sporomorphs are of simple morphology and with reference to KNOX 1950 it is suggested that they originate from such plants as Lycopods, Bryophytes and the like. A few of the more advanced forms of ancestral pollen are present in the so-called winged groups - the single winged or 'pre-pollen' and the biwinged or 'primitive pollen', which is generally believed to be the forerunner of the modern gymnospermous pollen.

The detailed description have been limited to the commoner forms, for which more data have been collected. The problematic forms such as 8a have been left for further consideration at a later date, when more may become known of its structure and affinities. This particular form is all the more interesting in that Balme and Hennelly 1955 report that it carries paired air sacs, which have no counterparts in the Ruhuhu specimens.

For similarity of constitution, the sporomorph flora should be comparable to that of the Barakar measures of Bengal, and the Greta measures of New South Wales. The forme r flora shows a relatively greater variety of the winged forms than does the Ruhuhu material. There is also a wide variety of the sporomorphs having superficial appendages. The general background flora is essentially similar though not as rich in the variety of spinose, warty and microreticulate forms. In the Greta measures, there is again the wide variety of winged forms, although the full range of spore forms is similar. The comparison here would be one of change of emphasis of one group of dominant spore producing plants in the New South Wales coals to an entirely different group in the East African material. As for the Natal coal, the paucity of the known flora limits comment to the noticeable fact that the bi-saccate forms are dominant, whereas they constitute but a small portion of the Ruhuhu flora.

S E C T I O N   II

T H E   I N V E S T I G A T I O N

P A R T   II

S E A M   C O R R E L A T I O N

Techniques and their application

SECTION II : THE INVESTIGATION

PART II : SEAM CORRELATION

(1) Description of Material

In both the palaeontological and stratigraphical parts of this investigation the same samples have been used. The investigation was intended as a stratigraphical exercise, for which the palaeontological aspect was a preliminary study - although its bearing on the whole investigation is such that it must be treated in more detail than the stratigraphical study. The limitations of an economic exploration of the coalfields has already been mentioned, and had to be accepted, and the desire to use this present work as an aid to practical identification of seams gave the study a somewhat economic bias in itself. The samples had to be limited to those from sampled economic seams and only these horizons have been considered; the majority of samples available were obtained from the coalfield with the greatest economic possibilities ie. Mchuchuma.

The Mbuyura samples, from the main Mkapa Trial Pit, were again used in the first stages of the study for experimenting with techniques to avoid wastage of the irreplaceable diamond drill cores. But the coal strata here are of a type not found in the other coalfields in the same form, and in themselves are of stratigraphic interest. The samples cover three sections, evenly spaced over 37 ft of strata, and each representing 2 ft of strata. Although only a few feet of coals are concerned it is reasonable to suppose that some differences would be apparent between the assemblages of sporomorphs extracted from the three samples.

The Mchuchuma Coalfield, being the most likely to come into production and hence the most interesting for which to attempt or confirm seam correlations, was the source of samples obtained from diamond drill cores. The cores were selected for the number of seams of economic value, and therefore sampled, that were passed through. In addition the fact that the number of seams that occur in the different parts of the coalfield is variable was taken into account in the selection of the cores so that it might be possible to trace the coalescing of two seams that was believed to occur. Borehole MC/8 was selected for its normal sequence of three economic seams with a fourth thinner seam which had been sampled. The Intermediate seam was also present but insignificant. Borehole MC/16 was selected because it was at no great distance from the previous borehole yet showed the alternative sequence of three economic seams of which the centre one was known to be the Intermediate seam and the one lying below it was believed to be the equivalent of the two lower seams of borehole 8.

(Unfortunately some of the borehole samples were mislaid until the end of the study and so the uppermost coals could not be compared)

(2) Techniques

(a) Sampling techniques

(i) Mbuyura (N. Ngaka) samples - from the Main Mkapa Trial Pit were the same as those used in the Palaeontological section, and the sampling has already been dealt with in some detail under the relevant headings in that section.

(ii) Mchuchuma boreholes - as already described under the palaeontological part, the borehole samples were prepared from chip samples from the half cores remaining after chemical analysis, and covered the full length of core selected for detailed study. The system of division into "sections' and 'sub-sections' was briefly dealt with. It can be recalled that each 'section' was of approximately two feet in length, and the 'sub-sections' were a matter of a few inches only, the actual division having been made for the specific gravity determinations of the proximate analysis.

Each 'sub-section' was crushed separately to pass successively, the BS mesh sieves sizes 8, 16, and 30 but excluding any fraction of less than 120 mesh size. The final powdered sample was quartered. Three quarters of this was retained as the 'sub-section sample' and stored for future use, the other quarter was combined with the same part of each of the other 'sub-sections' to form the 'section sample'. By this method, the 'sub-section' could be kept intact in case a recombination of samples in a different way was decided to be necessary, while a 'section sample' representative of the full 'section' was procured. Further quartering of the sample was done to give a maceration sample of 1-1½ gms.

To ensure that all samples were comparable, these sampling methods were strictly adhered to, regardless of size and proportions of the 'sections' and 'sub-sections' for only by constancy of procedure can the final samples be reliable. This aspect cannot be stressed too much for the final preparation on the slide must be representative of a coal sample many times its own size, and is produced by a series, of processes, not merely one or two.

(b) Maceration techniques

The standard procedure as set out in the palaeontological part, using Schultz solution was used throughout the stratigraphical study on the Ruhuhu coals.

In the case of certain outcrop coals (from Kivira Songwe) which were used for comparative purposes, the initial oxidising reaction of the Schultz solution was found to be too violent, and destroyed nearly all the spores present. The alternative method devised by Zetscoe and Kalin was employed for these samples. One of the disadvantages of the method that was encountered was that the final residue was resistant to the saffranin stain and so not directly comparable. For reference a brief description of the method is included.

A sample of about ¼ gm powdered coal was put into a polythene beaker and covered with hydrofluoric acid for 24 hours. After washing it was oxidised with fuming nitric acid for about 4 hours. It was then washed in a sintered glass funnel with fuming nitric acid, then conc. nitric acid, dilute nitric acid and finally distilled water. It could then be decanted off and stored in glass tubes as were the other samples. This method did not normally yield good clean residues from the Ruhuhu coals which appeared to need more drastic treatment.

(c) Microscopical techniques

The methods of mounting have already been described under the same heading in the Palaeontological part. Three slides were normally made from each of the prepared residues, being labelled A, B and C in strict order of mounting, the slides A and B were those used for the stratigraphical work; slide C was used as a precautionary measure to ensure that no rare spores were omitted.

In all spore counting the binocular body of the microscope was used with the x20 objective to give a magnification of about x350, with the use of the x40 objective if there was any doubt about the possible identity. A regular method of traversing the slide was evolved always starting at the NW corner of the cover slip, and progressing by means of a NS traverse with the EW scale of the mechanical stage being used to fix the next traverse at a distance on the scale of 0.8 divisions to ensure that there would be no overlap in the counting. The interval was set to give the traverses at approximately 1½ times the width of the field of view. Where fragmentary or eroded sporomorphs were encountered they were recorded as far as possible as being whole specimens of their original selves or placed as nearly as possible into their respective groups. The spore counts was carried out on specially designed sheets, recording the actual spores as they were seen and allowing totals to be taken at any stage in the proceedings. The use of these totals will be discussed in a later section.

(3) Analysis of results and accuracy in counting

At the time when the Ruhuhu coals were under investigation for their spore content, no work had been published on the statistical side of spore counting ie. no evidence was given anywhere as to how many spores constituted a reliable estimate of the population at any given point.

Various suggestions were made to the author on this topic; the first method actually used was to count all spores occurring on each slide from the preparation, whether the preparation itself had yielded a reasonable number of spores or only relatively few. This was felt to be rather unreliable as it offered no real comparison between counts from the same preparation nor between counts from different preparations. Eventually this method was superseded by a method devised for this investigation, in which slides already counted were used in experimental counting.

One school of thought was in favour of continuing a count until the dominant sporomorph reached an individual total of 100. Where the dominant form represented about 30% of the total this restricted the total count to as little as 330 spores. Except in cases where the slide was extremely poor in spores this was felt to be definitely too few individuals to give an accurate picture of the assemblage.

The NCB Coal Survey Laboratory staffs used a method in which the spore count was continued until the total number of spores counted was 2000. As has already been mentioned, it was rare that even 1000 spores could be found on a slide of the Ruhuhu coals so that this method would have involved making and counting several slides until the total did reach 2000!

The method finally used was based partly on each of the two preceding methods, in other words both the total numbers of spores counted and the total number of the dominant spore were taken into account. This method will be dealt with fully in a later section.

(a) <u>NCB Statistical study</u>

In 1957 a paper was published by R.C. Tomlinson of the NCB Scientific staff on the subject of reliability of spore counts and the operator. A discussion is included here although the work was too late to be of practical value in the investigation. The study undertaken was designed to check the accuracy of analyses made from the samples and to compare the interpretation of the analyses made by different workers.

In experimental preparation it was shown that the preparations made for the same samples by three workers using two different methods, and each resulting preparation studied by each worker, did not yield significantly different results. It was realised that errors could be introduced at the time of sampling and during preparation and counting. It was also shown that a bias could exist in the counting of one worker as compared with another, or from one occasion to another, when considering the commoner forms present. The bias may be partially due to the individual treatment of fragmentary spores. The errors in preparation were eventually shown to be similar for two samples of a seam taken close together as for two samples of a seam taken from different localities.

For each prepared slide spore counts to a total of 2000 spores were made. Two counts of 2000 spores made on the same slide and the average values taken showed approximately the same results as the single count on the 2000. However, if a second count was made on a slide from a different preparation, and the two results averaged, a better estimate of the true assemblage was thought to be given, in that a slightly different proportion of the spores present was obtained. The errors in the actual counting were shown to be small enough to be non-significant.

The conclusions are twofold: It is considered that a sample of 0.2 gms coal, prepared from a pillar sample of coal, and used for maceration, can and does give a representative analysis of the spore content of the seam in the neighbourhood of the sample, although certain negligible errors may be introduced at certain stages. It is also considered that the accuracy of counting can be improved by the use of two separate preparations, each involving a count of 2000 spores and averaging the results.

Attention was paid to the problem of presence and absence of rare forms. It is shown that absence of a spore type in a single count of 2000 spores does not necessarily mean it is absent from the full sample. Statistical data shows that there may be a range of from 0.0 to 4.6 spores present when a count of 2000 gives a zero value. Indeed it is not until 5 spores are recorded in a count that one can expect to find at least one of that type in every count of 2000.

This paper is significant in being the first available statistical study dealing with the problems of sampling and counting of spore preparations. Even so, there are many gaps in the data, and the study has only been for a small number of samples and covering the work of three people only.

(b) Preliminary spore counts for Mbuyura

For the Mbuyura samples several preparations were available for each sample, having been produced by experimenting on oxidation times for the sample. The useful range of preparations covered oxidation times of from 24 to 48 hours and consisted of a series of four, the shorter times of 18 and 21 hours being rather 'underdone'. Two slides per preparation had been made and a possible total of eight slides were available. Each slide was completely traversed during counting and a full count of all spores made according to their more distinctive features i e ornament and suture. Any really distinctive types were separated out from the rest into smaller groups. Total numbers of spores counted for this and the number of slides involved is given below:

MB/1 8 slides totalling 3,830 spores
MB/3 6 slides totalling 1,450 spores
MB/6 7 slides totalling 2,210 spores

An analysis was made of each sample from the total number of spores encountered on the slides and individual groups of spores were shown as percentages of the full population in the spore assemblage for the sample. Histograms were used to represent the percentages diagrammatically, and certain distinctive groups could be picked out to give a more detailed seam assemblage. (Figs 11 and 16.)

(c) <u>'Strip traverse' analysis of slides to check reliability of spore counts.</u>

In the initial stages of a work it is quite understandable that doubts will arise as to the accuracy of the results produced and their reproducibility in further samples of a similar kind. This was the case where no data could be found on which to base the level to which spore counts should be taken in order to get results that would be both reliable and able to be reproduced. The question was - what was the minimum number of spores which should be counted per slide to give a reliable estimate of the relative proportions of the main sporomorphs present, and how could this be checked?

Two slides were chosen from each sample from Mbuyura - the ones for the 24 hour maceration were selected as they appeared to give the most abundant spores as seen in the preliminary counts. They were thus directly comparable, and as both slides for the one sample were from the same preparation they too should be comparable, if not quite the same, at least similar.

It was felt that somewhere between the two extremes of counting - i e the 2000 spores per slide method and the 100 dominant spores per slide method - that a suitable figure could be found that would give a reliable estimate of the spore assemblage on the quantity of spore material available from the Ruhuhu coals. The ideal would be to locate a level during counting at which the percentages of each type relative to the total became more or less steady, and after which little or no change in the percentages could be noticed.

The method adopted for the analysis was based on the petrographical 'point count' method which makes use of a mechanically propelled stage in both a NS and EW direction, the operator recording only those constituents that come to rest beneath the cross wire at each move. The resultant coverage is a regular meshwork of points recording the actual mineral content of the slide.

In adopting the method an ordinary hand operated mechanical stage was used. Each traverse was done in the NS direction the EW position of the scale being determined by a regular traverse interval of 0.8 divisions as already mentioned. Instead of using only the central point of each field of view the whole of the field was used - hence the traverse represented a full strip of the slide. In effect a series of strip traverses were made in the NS direction evenly spaced across the slide. Every sporomorph in each strip was recorded for the count. It was found that roughly 27 traverses were needed for the full coverage of a slide with 7/8 inch cover slip. At the end of every traverse the number of each spores type counted was recorded on a separate sheet from the actual count, the running total of each spore type could thus be seen and their progressive percentage of the total count at each stage calculated and plotted (Figs 7-9). From these percentages the variation of the major elements of the assemblage could be plotted on a graph of traverse number against the percentage recorded. By this means it was possible to show

(i) when the dominant sporomorph reached and maintained a reasonably constant percentage of the full recorded assemblage;

(ii) when the rest of the population would reach a similar constant percentage and

(iii) whether both the dominant and sub-dominant types would maintain that level relative to each other over the rest of the count (if indeed this could be accomplished on one slide).

The resulting graphs are appended (Figs 7-9) and show the following features:

(i) In the first few traverses of each slide the percentages of the selected forms fluctuated greatly due to the small numbers of spores involved. The rarer forms will always show this tendency as one or two individuals may alter the relative value of the spore.

(ii) When the total of the dominant sporomorph reached 50 the graph continued to fluctuate and this situation continued until well after the 100 level for the dominant.

(iii) Between 150 and 200 the dominant sporomorph showed a definite tendency to ~~maintaining~~ maintain a steady level of percentage. Little change occurred between that position

FIG. 7

STRIP TRAVERSE ANALYSIS OF SLIDES

PROGRESSIVE PERCENTAGES OF SELECTED SPORE FORMS

MBUYURA SAMPLE 1

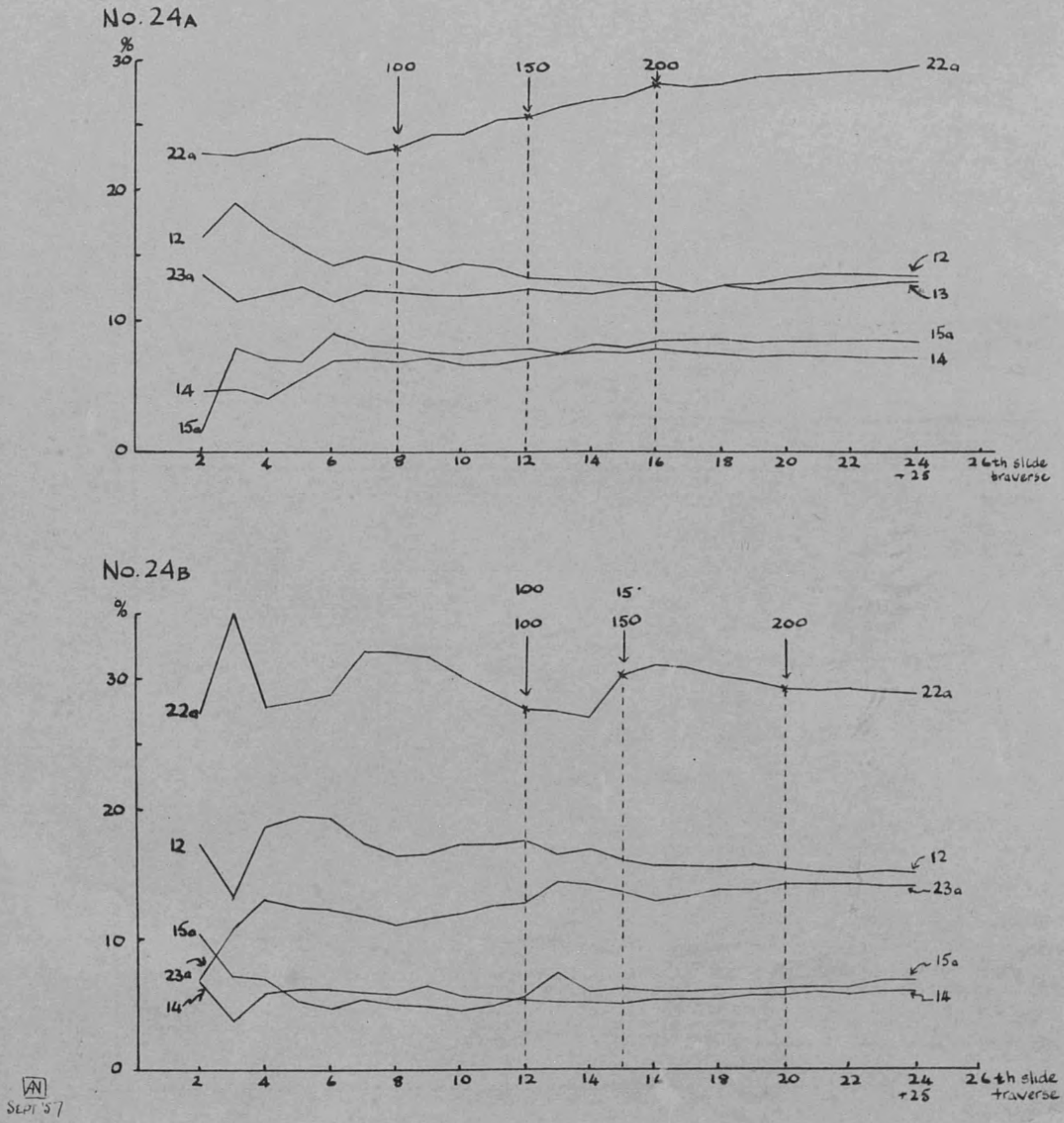


Fig 8

Strip Traverse Analysis of Slides

Progressive percentages of selected spore forms

Mbuyura sample 3

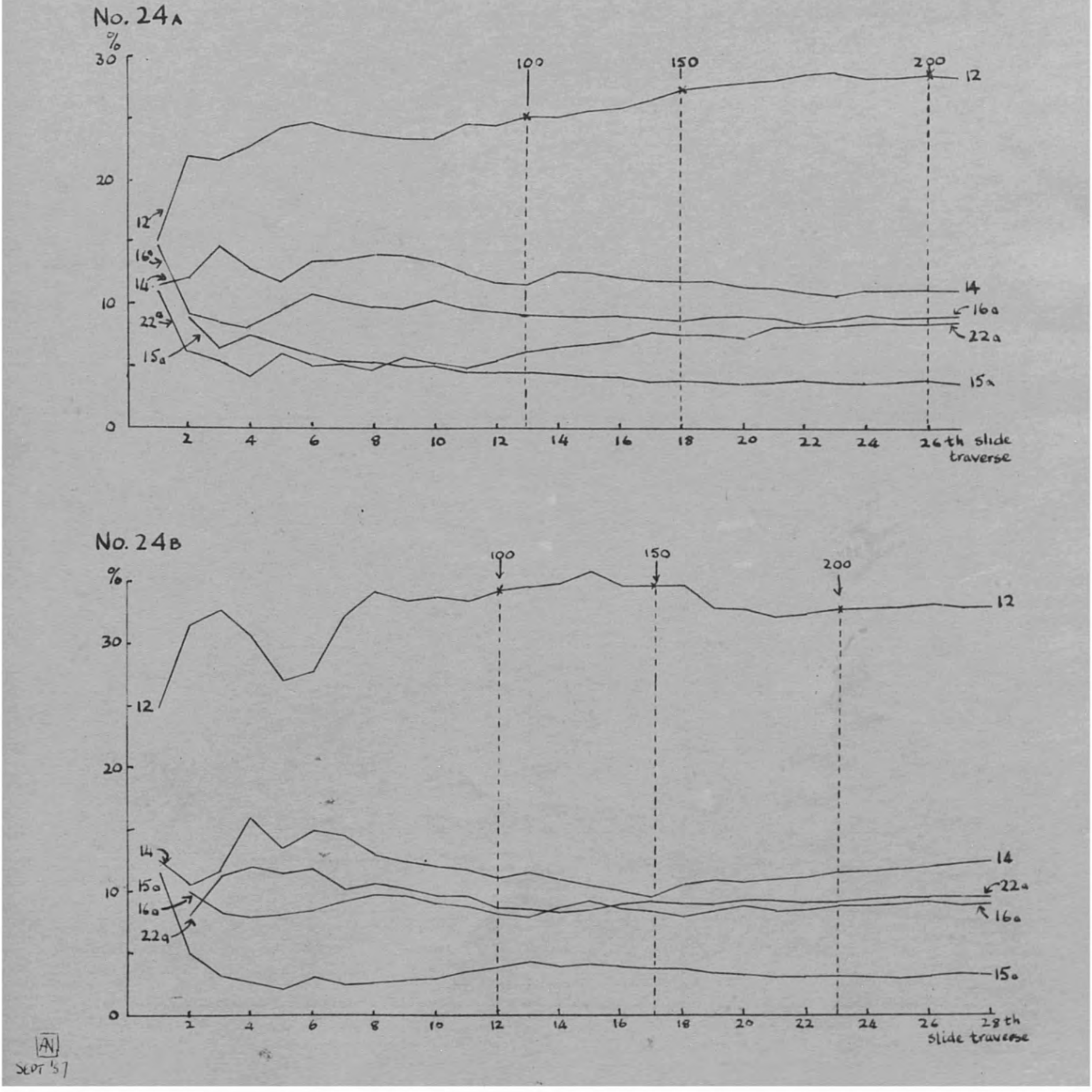


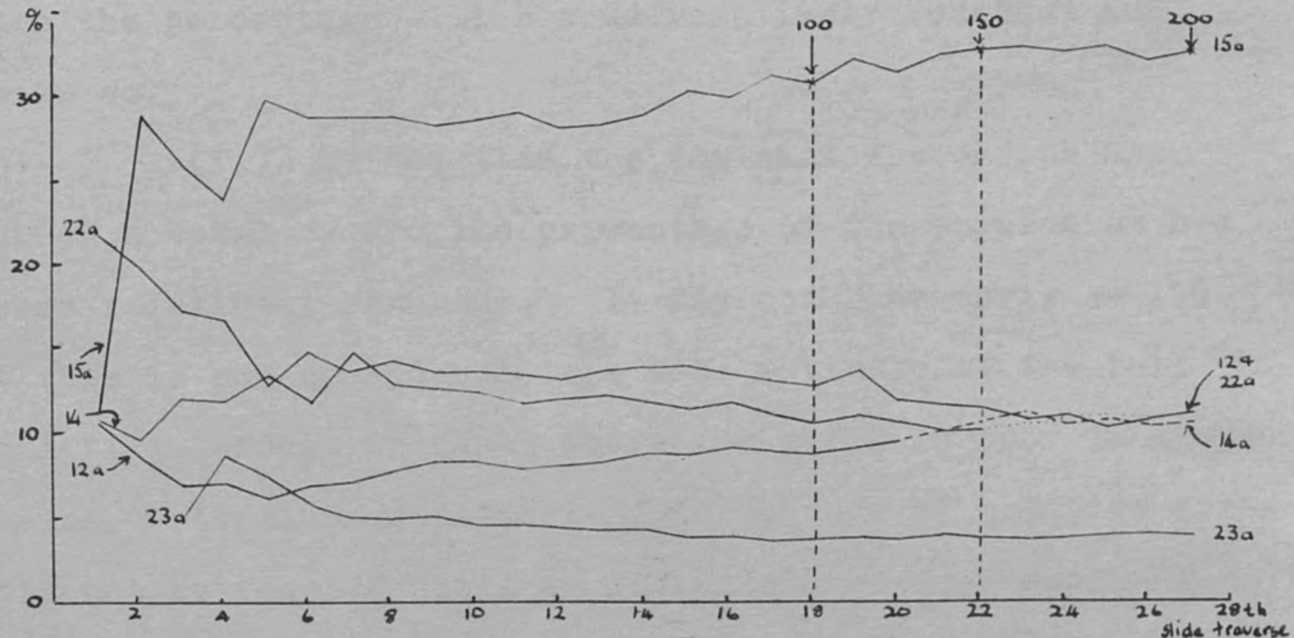
FIG. 9

STRIP TRAVERSE ANALYSIS OF SLIDES

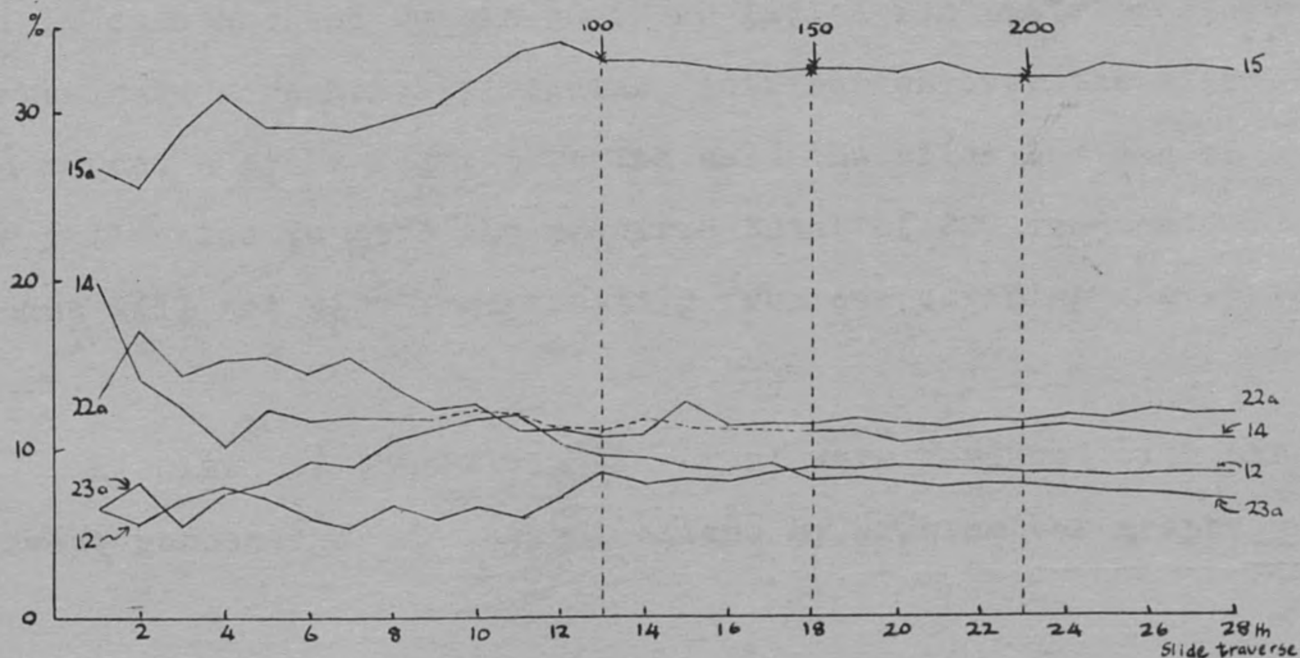
PROGRESSIVE PERCENTAGES OF SELECTED SPORE FORMS

MBUYURA SAMPLE 6

No. 24A



No. 24B



AN
SEPT '57

and the end of the count.

The conclusions reached on this were as follows:

(i) As the total number of spores increases, so does the constancy of the percentage of any of the commoner elements of the assemblage become noticeable. At a certain stage the percentage will become relatively constant and remain so.

(ii) By the time the dominant sporomorph has reached a total of 200 its percentage of the population has become relatively constant. It may occur as early as 150 but this is not considered to be a safe estimate of the full population, except in cases where the slide is poor in spore remains. Absolute constancy of percentage of the population would not be reached until an infinite number of spores had been counted.

(iii) The fact that the percentage levels do become fairly constant and remain so is an indication that the sporomorphs have a reasonably regular distribution over the slide, and hence, a spore count covering half the slide instead of the full slide to give the required total of 200 dominant spores will not vary significantly from one covering the whole slide.

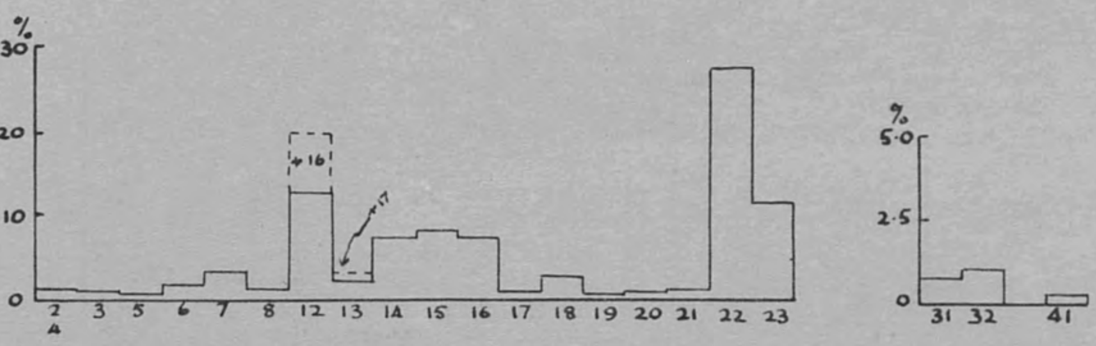
Results of the 'strip traverse' were compared with the average percentage for several slides by drawing bar graphs

Fig. 10.

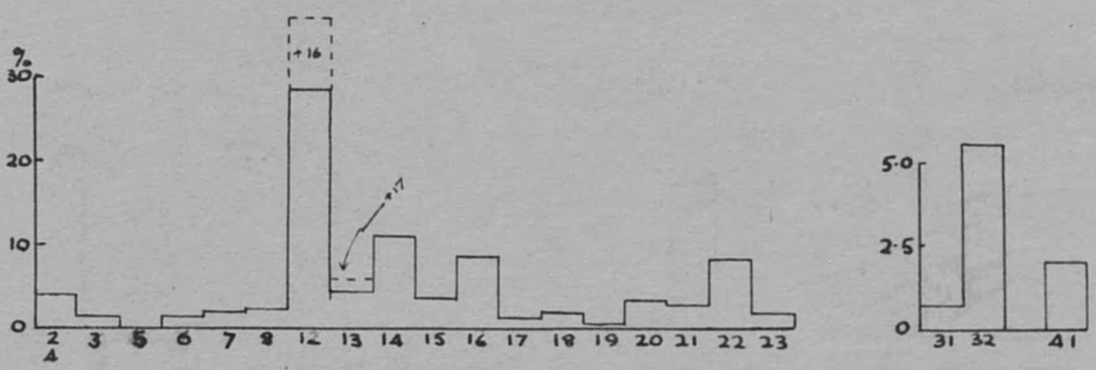
Comparisons of Mbuyura Spore Counts

I. Strip Traverse Method - 1 slide/sample

Mbuyura Sa. 1 No. 24a.



Mbuyura Sa. 3 No. 24a.



Mbuyura Sa. 6 No. 24a.

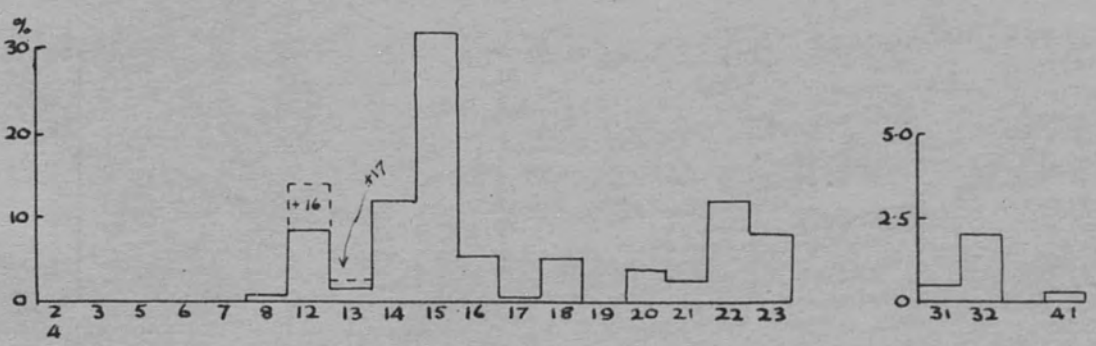
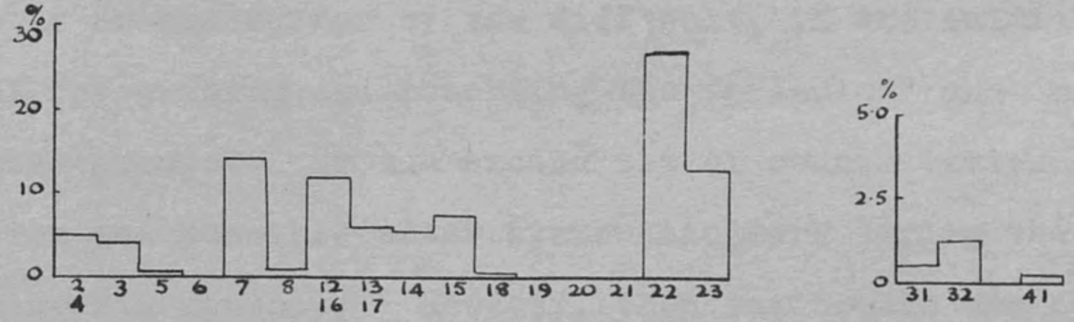


FIG. 11

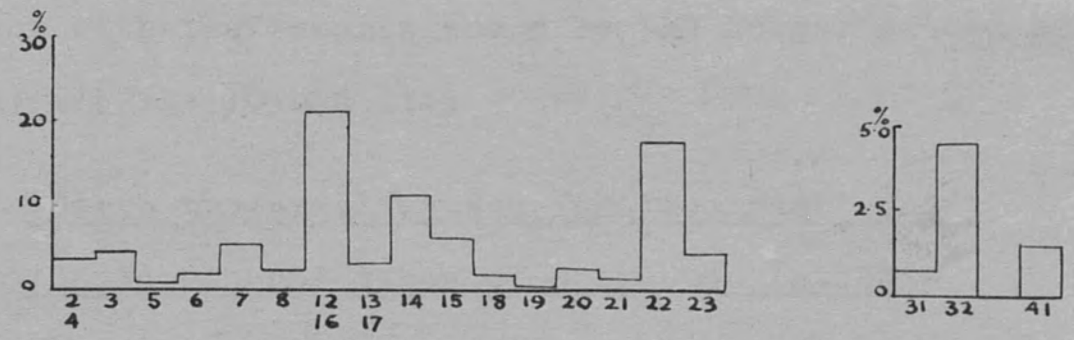
COMPARISONS OF MBUYURA SPORE COUNTS

2. TOTAL POPULATION - 6 TO 8 SLIDES/SAMPLE

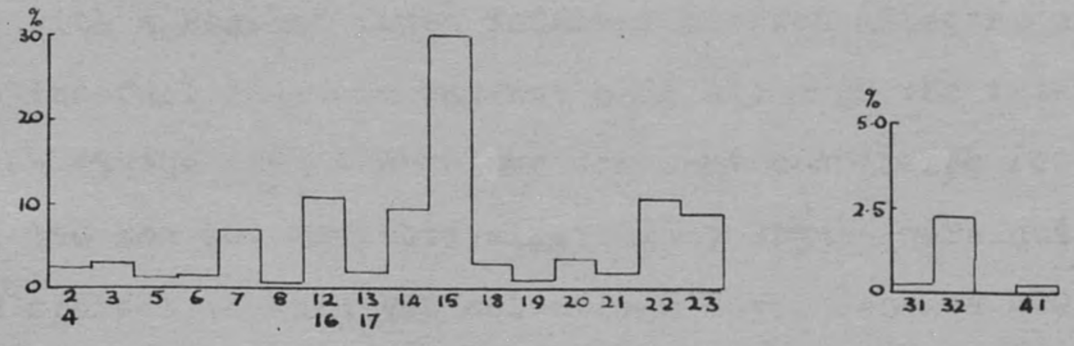
MBUYURA SA. 1



MBUYURA SA. 3



MBUYURA SA. 6



AN
SEPT '57

for the two sets of data using the same groupings for the sporomorphs. The numbers of sporomorphs involved were for MB/1 3830 by the averages method and 1410 by the 'strip traverse' method for MB/3 1450 and 1314 respectively, and for MB/6 2210 and 1211 respectively. (The fact that a greater number of spores per slide were recorded in the second count for MB/3 is accountad for by the difficulty in the initial stages of recognising and recording the 'granular' and 'micro-reticulate' groups. By the second set of counts better recognition was possible after systematic work during the intervening six months.) However, when the totals are combined into similar groups, the resulting histograms are comparable, showing that the later more detailed analyses are consistent with the results shown by the longer method of averages. (Figs 10 and 11.)

(d) <u>'Strip traverse' system for 'dominant' and 'non-dominant' types of spore population</u>

The method used during the 'strip traverse' reliability check was utilised for all subsequent counting - namely a NS traverse with a regular fixed interval between adjacent ones. In these the full analysis was not made although the totals were taken at the stages when the dominant sporomorph reached 50, 100, 150 and 200 respectively. Also totals were noted for each spore type when the assemblage total reached 400, 500, 600 etc as a check on the required number of spores in a count where no actual dominant was present but possibly two sub-dominant forms could be recognised. In this aspect, it was found that for the 150 dominant form a total of between 450 and 550 had been counted, and for the 200 safety level the totals were roughly between 625 and 725. For a dominant population type a count of not less than 500 spores could be used as an alternative to 200 dominant sporomorphs. (If a single slide only is being used to estimate an assemblage then at least 700 should be counted to gain a reliable percentage.) **Two slides** would then give an overall total of 1000 spores, which is well within the safety level of 200 dominant sporomorphs. For a slide of unknown potentialities, or for one known to contain two or three subsidiary types rather than one dominant type, it is safe to assume that two counts from a pair of slides, each of 500 sporomorphs would give a reliable estimate of the population besides giving a simple calculation for the percentages!

(e) Representation of results

For all stratigraphical results the spore counts of each sample (usually 2 in number) were combined, and the average percentage calculated for each spore form. In the final stages, when the spores counted per slide numbered 500, the total count was based on a count of 1000 spores.

The resulting averages have been represented diagrammatically in two forms.

(i) By the use of histograms giving the actual percentage of each spore type. The value of this type of diagram lies in the obvious contrast between the major and the accessory spore types. The former are easily depicted but on the same scale the latter comprise a collection of low values with little distinction between types. If the major spore types are taken together with a selection of the more outstanding accessory types, a second diagram can be constructed to show the essential character of the seam assemblage.

(ii) A second type of bar-graph can be constructed utilising the relative frequency of the spores in contrast to their actual percentages. By this method it is possible to construct a continuous diagram for adjacent samples from a single seam, where the relative abundance is represented by the width of the bar. Care must be taken when selecting the intervals to be used to depict the relative abundance. Of necessity, unequal intervals of the percentages must be utilised, and if not chosen with care, the resulting graph may prove misleading. For this study the following intervals have been used:

less than 1.0% (trace)

1.0%-2.0%

2.1%-5.0%

5.1%-10.0% (abundant)

10.1%-15.0% (sub-dominant)

15.1%-25.0% (dominant)

greater than 25.1%

The former method was used for the Mbuyura samples where only a few samples were available at intervals through the coals, while the borehole core samples from Mchuchuma have been subjected to both methods of representation, for continuous seam samples enabled the results of the counts to be summarised by the second method.

(4) Samples from the Ngaka Area - Mbuyura Coalfield

(a) Relationship of samples

In the previous section on palaeontology, it was mentioned that the principal samples used were from the Main Mkapa Pit in the coal series of the Mbuyura Coalfield. These samples were selected in the first place to enable the preliminary work to be carried out on a virtually unlimited supply of coal. Each of the laboratory samples of 2 lbs was a representative sample taken from a large box by random sampling methods. The three samples selected were taken at equal intervals over the 36 ft of coal available, each sample covering about 2 ft of coal seam. The three samples could thus be taken as representative of the top, middle and bottom sub-sections of the coal section sampled from this pit. These samples (numbered by the CDC geologists) were as follows:

MB/1	95 - 97 ft	below surface
MB/3	112 -114 ft	below surface
MB/6	129 -131 ft	below surface.

No information was available on the chemical constitution of the coals as the full section of coal had not reached England and hence had not been analysed. The average proximate analysis for Mbuyura coals shows about 56% fixed carbon, 24% volatile matter and 16% ash.

It was hoped that the interval of 15 ft between the samples would prove large enough to be able to find noticeable differences in the spore populations extracted from the three samples. For if this were so the results would warrant the investigation of the spore content of the seam sequence in the Mchuchuma borehole cores

(b) The microfloral assemblages

For each of the three samples the relative abundance of each distinctive sporomorph was calculated as a percentage of the full assemblage present in the count. This included broken but recognisable forms, so that as few specimens were omitted as possible. The spore assemblages have been summarised as histograms (Figs 13 and 14). The full range of spore types has been used in the first place, while the more outstanding features have been extracted as seam diagrams (Fig 15). The percentages for the second diagram were recalculated on the total number of spores involved, and are therefore an exaggerated portion of the previous diagrams.

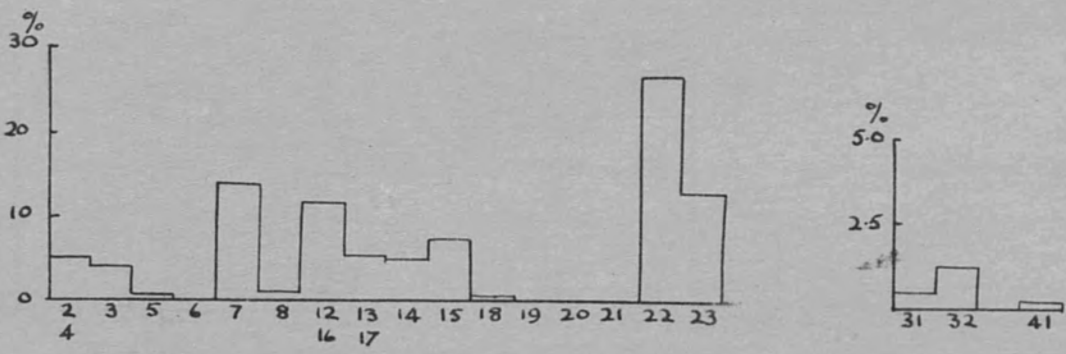
From these diagrams it can be seen that the most useful of the sporomorphs in the seam assemblage are the simple trilete forms, with the possible exception of 8a (monolete) and the form taken by that part of the graph occupied by the winged forms. The monolete forms have not been divided up into 'species' as have the trilete forms, so that this may

Fig. 13.

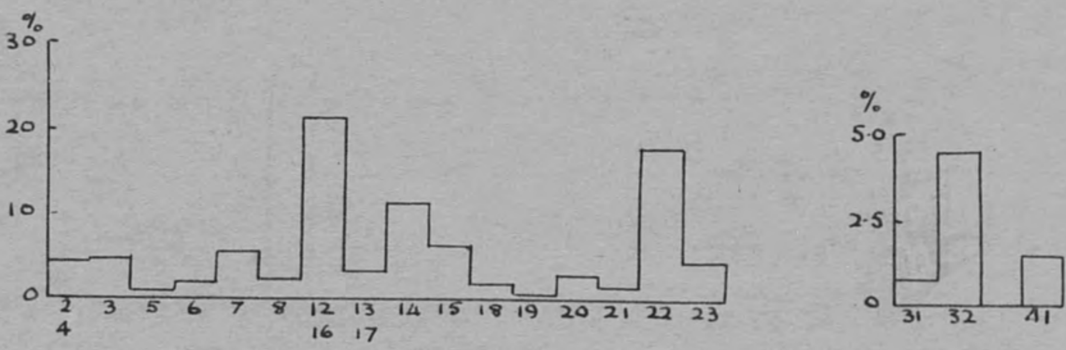
Mbuyura Spore Populations

I Total Spore Count

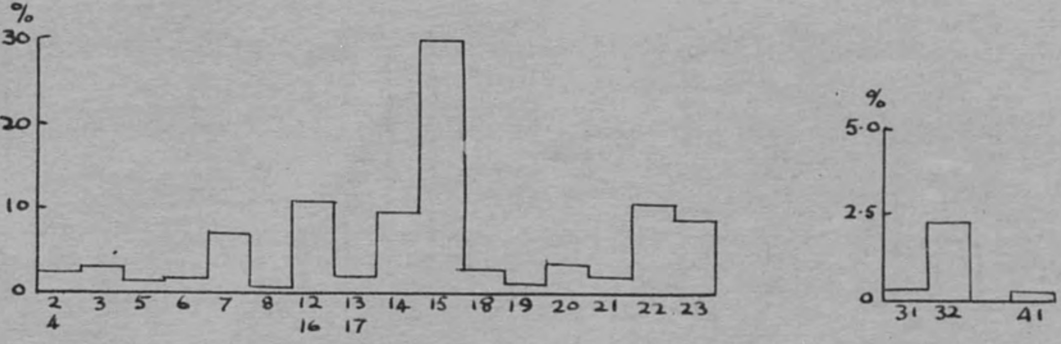
Mbuyura Sa. 1



Mbuyura Sa. 3



Mbuyura Sa. 6



AN
Sept '57

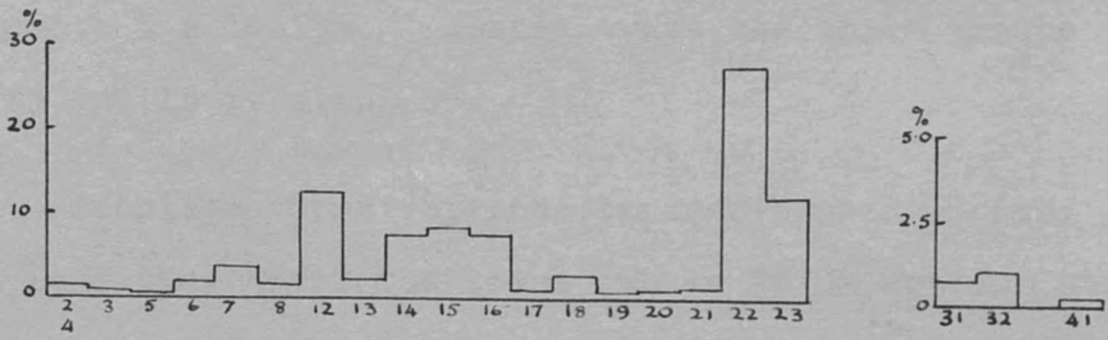
FIG. 14

MBUYURA SPORE POPULATIONS

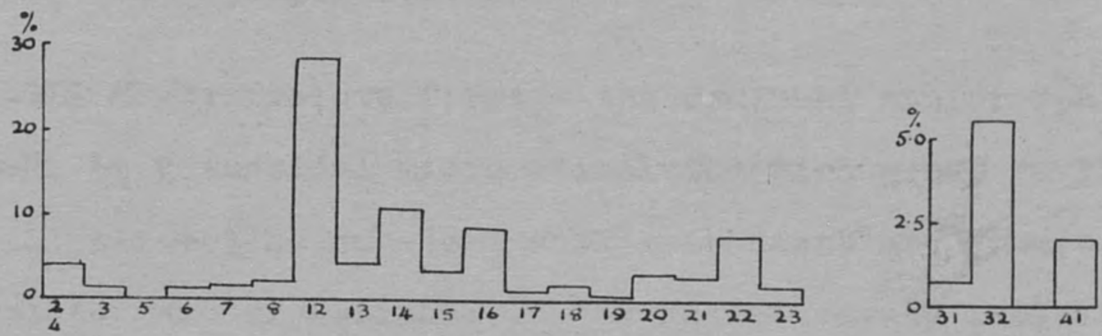
2. SINGLE SLIDE – DOMINANT SPORE

TOTALS-200

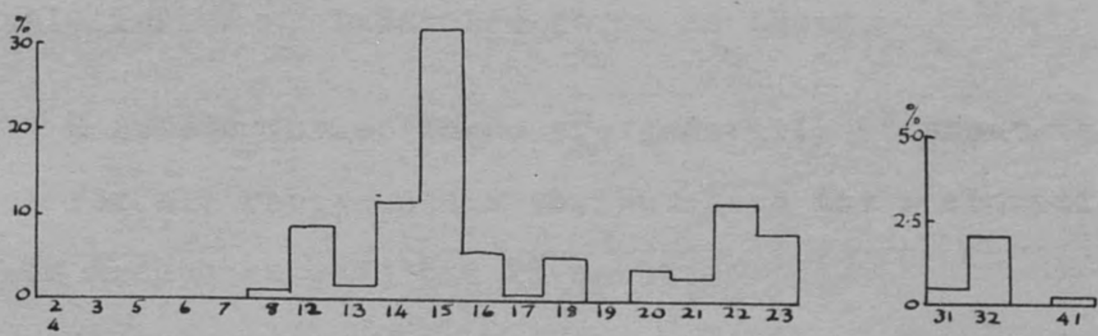
MBUYURA SA.1 - NO 24A



MBUYURA SA 3 - NO 24A.



MBUYURA NO.6 - NO 24A.



account for the less reliable nature of their occurrence.

General features of each assemblage: (Figs 13-15)

SAMPLE MB/1: Trilete forms - dominant sporomorph i e over 15% is the discoidal spinose form, with the groups 23 (triangular spinose and 12 (discoidal microreticulate) as sub-dominants i e 10-15%. Abundant are the three groups Nos 14, 15 and 16 at about 8%.

Monolete forms: Spinose ornaments predominate, although less than 5% of the total, while No 8a appears at about 3%.

Winged forms: The three groups are each represented but only in small proportions.

SAMPLE MB/3: Trilete forms - the dominant sporomorph group is No 12 (discoidal microreticulate) with group No 14 (discoidal psilate) as sub-dominant. Abundant are groups 16 (granulate) and 22 (spinose). It is noticeable that the spinose forms are suppressed compared with the previous assemblage, as are group No 15 (triangular psilate). However, a noticeable influx of tubercled forms is shown.

Monolete forms: These are generally at about the 1-2% level for all representatives, but both the microreticulate and striate groups surpass the 2% mark.

Winged forms: All three groups are well represented for these forms. The trilete monowinged group reach 5% and the bisaccate forms total about 2%.

SAMPLE MB/6: Trilete forms - the dominant sporomorph group at over 30% is No 15 (triangular psilate). Groups 22 (spinose) and 14 (discoidal psilate) are sub-dominant, but do not reach more than 12%. Abundant at just over 5% are the groups 23 (spinose triangular), 12 and 13 (microreticulate). Noticeable are the verrucate forms of group 18.

Monolete forms: Rare except No 8a.

Winged forms: Representatives of all three groups present, but only the trilete monowinged form appears as more than a trace.

(c) <u>Distinctions between the three samples</u>

Mbuyura Sample 1 is characterised by a high proportion of spinose forms, with other finely ornamented forms as the background population, while coarsely ornamented forms such as verrucate and tuberculate, are present in small proportions only. The winged forms show variety but are not abundant.

Mbuyura Sample 3 - 15 ft lower in the succession shows a marked predominance of the finely ornamented forms, both granulate and microreticulate. Verrucate and tuberculate forms are present in small quantities only, although the latter are more numerous than in the higher sample. In

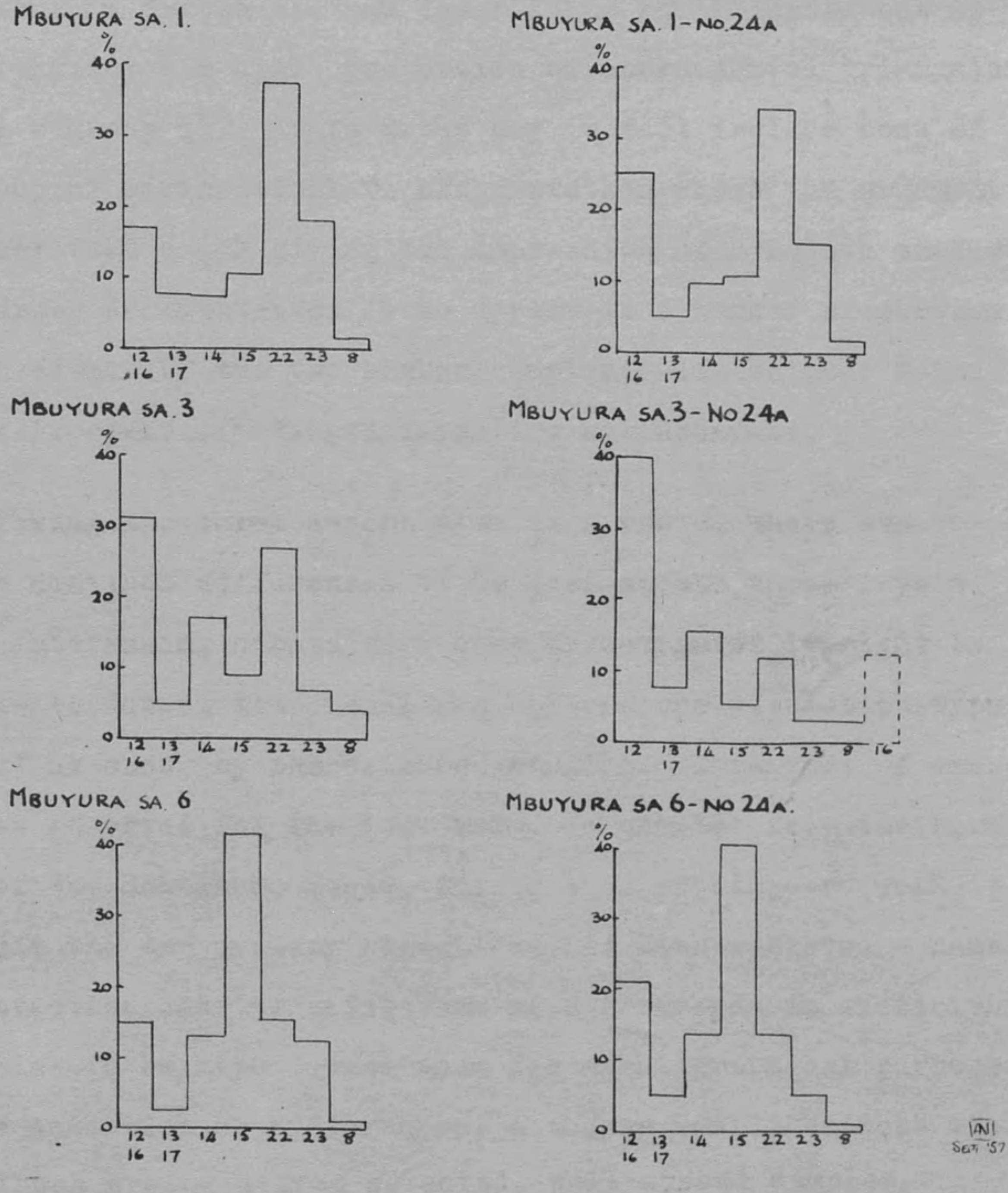
Fig. 15

Mbuyura Spore Populations

3. Seam Assemblages of Important Forms

(i) Total spore Count

(ii) Single slide - 200 dominant spores



INI
Sep '57

direct contrast to MB/1 the spinose forms are only a minor constituent of the assemblage. The winged forms too show both a variety and abundance lacking in the previous sample. The whole assemblage is one of uniformity of proportions with a preponderance of the more finely ornamented forms.

Mbuyura Sample 6 - has fewer forms recognisable but is noteworthy for the high proportion of unornamented triangular forms i e group 15. This group may in fact include some of the group of microreticulate ornamentation where the ornament was finer than usual giving the impression of a smooth surface. The coarser ornamentation forms appear in a higher proportion than in either of the two higher samples, with spinose forms relatively common. Winged forms are not abundant.

Taking the three assemblages as a whole, there are certain distinct differences to be seen at the three levels. If the intervening strata were also investigated it might be possible to detect the transition between one population type and the next as shown by the selected samples. This sort of exercise has been reserved for the more valuable samples from the borehole cores of the Mchuchuma field, for in this preliminary work it was seen that the two primary objectives had been achieved - namely the extraction and identification of sporomorphs in sufficient quantities to be able to use them for stratigraphical purposes, and the detection of differences, although small, between the assemblages produced from selected, well spaced samples.

(5) Samples from the Kitewaka Area - Mchuchuma Coalfield

(a) Relationship of samples and method of approach

The selected boreholes for this more detailed study were from near the middle of the Mchuchuma basin of coal deposition, but although less than ¼ mile apart showed differing sequences - that of MC/8 being the normal sequence in which were recognised the Top, Middle and Lower Economic seams together with an uneconomic small seam between the Top and Middle Seams, the Intermediate Seam. The sequence in MC/16 showed an alternative succession of Top, Intermediate and Thick Economic Seams, in which the latter was assumed to have been formed by the coalescing of the Middle and Lower Seams.

Figure 16 shows the relationship of the samples from the two boreholes diagrammatically, the samples used being from the economic seams only. The samples correspond as nearly as possible to the sections and sub-sections into which the cores were divided in the course of analysis at the Fuel Research Station at Greenwich. In the succeeding pages a list is given of the samples used in each borehole with details of depth, thickness and proximate analysis where possible for each sample.

To begin with samples were selected from certain levels in the coal series which were believed to correspond in the two boreholes, much as in the previous work, to check whether these apparently equivalent levels were in fact the same. The samples chosen were limited by the availability of material and consisted of four groups as follows:

MC/8

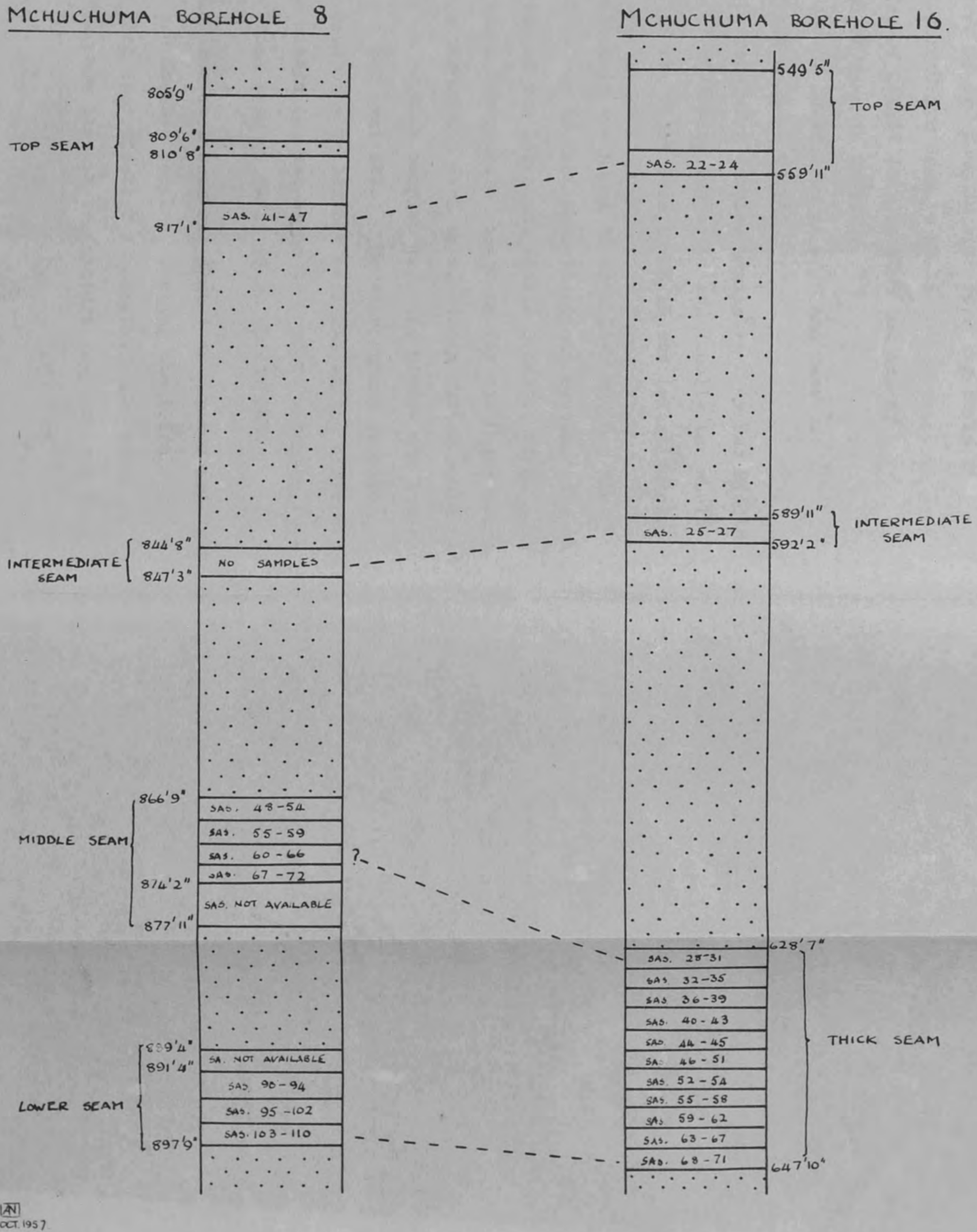
	Samples	Depth	Sp.G.	Moisture	V.M.	F.C.	Ash
TOP SEAM							
	41-47	815'1"-817'1"	1.38	1.4	27.1	60.6	10.9
MIDDLE SEAM							
3'9"	48-54	866'9"-868'8"	1.37	1.8	23.2	66.1	8.9
	55-59	868'8"-870'6"	1.41	1.8	21.7	64.2	12.3
	60-66	870'6"-872'4"	1.49	1.6	22.5	60.4	15.5
	67-72	872'4"-874'2"	1.41	1.6	24.4	61.3	12.7
7'5"	73-77	874'2"-876'1"	1.42	1.5	26.6	59.8	12.8
	78-83	876'1"-877'11"	1.38	1.5	25.7	63.4	9.4
LOWER SEAM							
	84-89	889'4"-891'4"	1.40	1.6	22.3	66.5	9.6
8'5"	90-94	891'4"-893'6"	1.43	2.0	21.8	64.0	12.2
	95-102	893'6"-895'8"	1.40	1.5	23.9	61.6	13.0
	103-110	895'8"-897'9"	1.38	1.3	29.1	57.5	12.1

MC/16

	Samples	Depth	Sp.G.	Moisture	V.M.	Fixed C.	Ash
				Analysis %			
TOP SEAM							
	22-24	558'5"-559'11"	1.47	1.6	23.3	55.0	20.1
INTERMEDIATE SEAM							
	25-27	589'11"-592'2"	1.38	1.8	23.8	58.4	16.0
THICK SEAM							
4'10"	28-31	628'7"- 630'3"	1.48	1.8	23.4	59.5	15.3
	32-35	630'3"- 631'10"	1.41				
	36-39	631'10"-633'5"	1.39				
4' 7"	40-43	633' 7"-634'8"	1.65	1.1	32.0	39.4	27.5
	44-45	634' 8"-635'8"	1.41	2.0	20.9	61.7	15.4
	46-51	635' 8"-638'2"	1.52				
9' 8"	52-54	638' 2"-639'6"	1.43	1.7	22.1	59.2	17.0
	55-58	639' 6"-641'7"	1.53				
	59-62	641' 7"-643'11"	1.48				
	63-66	643'11"-645'8"	1.47				
	67-71	645' 8"-647'10"	1.48				

Fig. 16.

Relationship of Samples used from Mchuchuma Boreholes Nos. 8 & 16



1. Base of TOP Seam in both MC/8 and MC/16
2. INTERMEDIATE Seam in MC/16
3. Top of MIDDLE Seam in MC/8 and top of THICK Seam in MC/16
4. Base of LOWER Seam in MC/8 and base of THICK Seam in MC/16.

Subsequently, the remaining samples available from the Middle and Lower Seams of MC/8 were inspected and finally the whole of the sequence of the Thick Seam in MC/16 was investigated.

By this method it was hoped to establish whether the Thick Seam of MC/16 was in fact equivalent and contemporaneous with the depositon of the Lower and Middle Seams of MC/8. It was hoped to produce distribution diagrams for the major spore forms, continuous throughout each seam. This latter could not be completed as certain samples from the Middle and Lower Seams of MC/8 were not available. However enough samples were present to produce a reasonable estimate of the distribution of spores within the two seams to compare with the full sequence in the Thick seam of MC/16 (Figs 25 and 26).

Each sample from each seam has also been represented by a histogram as in the Mbuyura samples, showing the floral assemblages for each approximate 2 ft sample. The chief value in these diagrams lies in the picture they present in the relative changes and the development of the microflora between the base of the Lower economic seam and the base of the Top economic seam (Figs 17-24).

Throughout the paragraphs on detailed seam assemblages the procedure of working from the top of the seam downwards is followed, this being the natural outcome of the use of borehole cores from a mining investigation. Hence sections and sub-sections have been numbered in this way following the labelling of the actual samples by the field workers. However, in considering the seams as a whole, and in the discussion of the microfloral assemblages in relation to deposition of the coals, the normal stratigraphical procedure of commencing with the earliest beds and working towards the more recent deposits has been followed.

(b) Microfloral assemblages

(i) Selected horizons as given on page 158 - 159

1. TOP SEAM: Basal sample of approximately 2 ft thickness from Boreholes MC/8 and MC/16 (Fig 17).

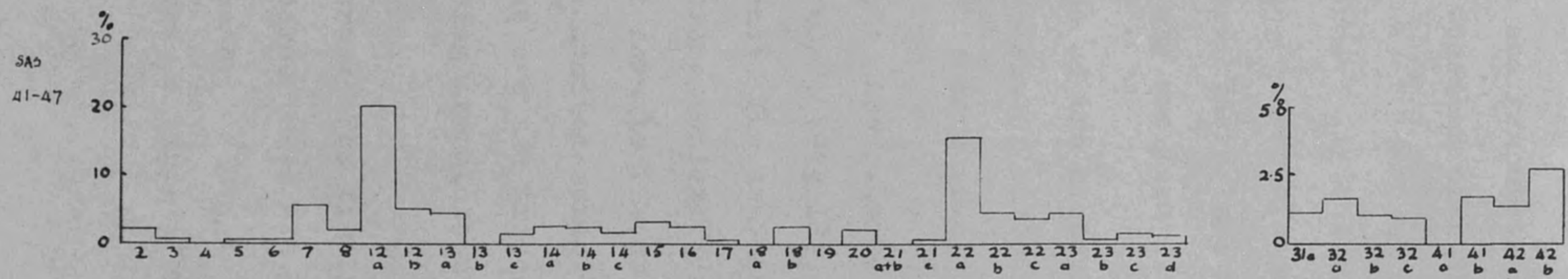
Trilete forms: The dominant spore is 12a in each case, at about 20%, the remaining microreticulate forms being at a general level of 5%. The sub-dominant spore is 22a with the remaining discoidal spinose forms at the 5% level in MC/8 but in MC/16 a higher proportion of 22b and lower of 22c are

Fig. 17.

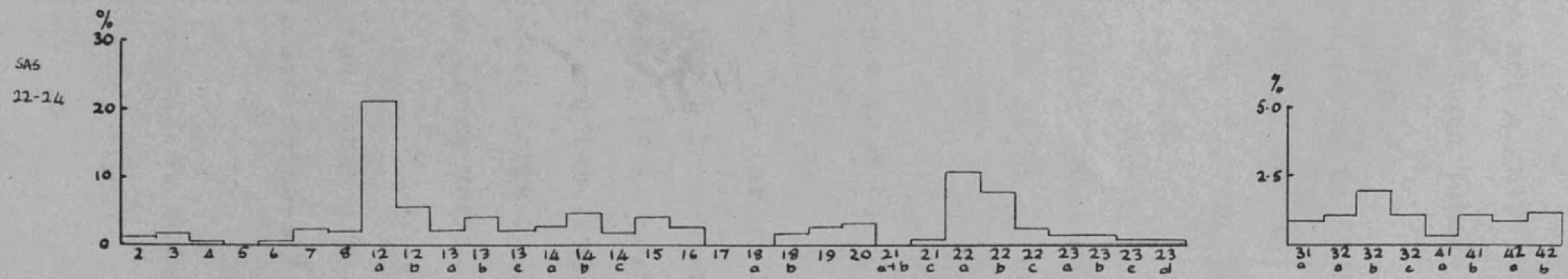
Mchuchuma Spore Assemblages

I Top Seam - basal 2feet sample - 2 boreholes

Mchuchuma borehole 8



Mchuchuma borehole 16



AN
Sept '57.

present. The psilate and granulate forms are not significant in either assemblage, together with the verrucate and tuberculate forms.

Monolete forms: All but the spinose forms in MC/8 are below 2.5% with the coarser ornaments relatively rare.

Winged forms: There is a good variety of form, but not more than 2.5% of any one form except 42b in MC/8.

The general shape of the histograms is similar though not the same in the two cases, but similar enough to be of the same type and hence contemporaneous.

2. INTERMEDIATE SEAM: Approximate 2 ft sample from borehole MC/16 (no sample from MC/8) (Fig 18).

Trilete forms: The dominant spore is 12a (about 20%) with the remaining microreticulate forms at a level less than 5%. The sub-dominant form is 22a at over 10% and 15 at nearly 10%. The coarsely ornamented forms (verrucate and tuberculate) are relatively rare, as are the triangular spinose forms 23b, c, and d. The remaining granulate and spinose forms vary between 2.5 and 5%.

Monolete forms: The finely ornamented forms are poorly represented, coarser ones are absent except spinose and striate at over 2.5% each.

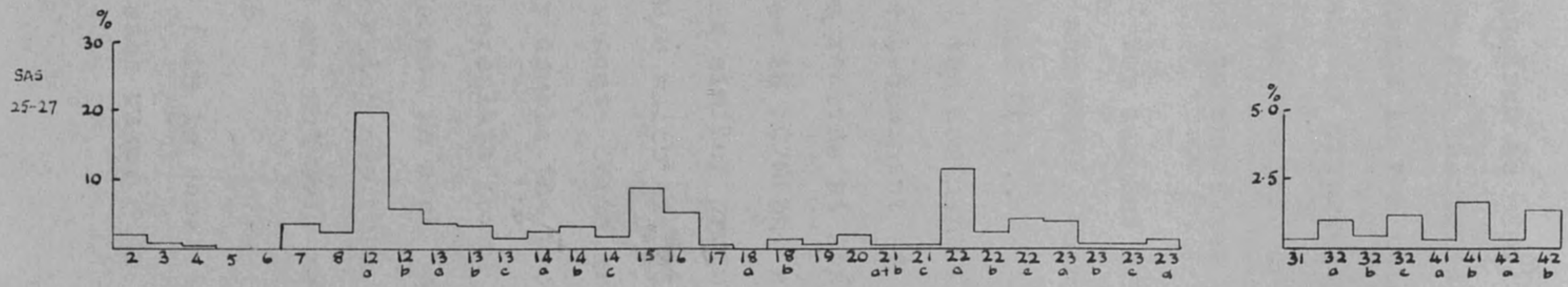
Winged forms: A variety of forms is evident but not abundant.

FIG. 18

MCHUCHUMA SPORE ASSEMBLAGES

2. INTERMEDIATE SEAM - TOTAL SEAM SAMPLE - 2 FT. APPROX.

MCHUCHUMA BOREHOLE 16



AI
SEPT '57

The general shape of the histogram is similar in form to that of the base of the Top seam for the trilete and monolete sections, which suggests little change in the intervening strata. The winged forms however, show a widely divergent form in the graph in that the single winged forms are less common, and differently distributed with regard to the types present.

3. MIDDLE SEAM and THICK SEAM: Top samples of approximately 2ft thickness from boreholes MC/8 and MC/16 Samples (48-54) and (28-31) respectively (Figs 19 and 20).

Trilete forms: In MC/8 the dominant form is No 20 at nearly 25%, having 12a as the sub-dominant at about 15%. In MC/16 No 20 reaches 30% but 12a remains at 15%. The micro-reticulate forms are relatively few in MC/8 but stand at about 5% in MC/16. Psilate forms are in similar proportions in the two samples except for No 15 in MC/8 which exceeds the general level of 2.5%. Granulate and verrucate forms are relatively rare except No 16 which has nearly double the proportion in MC/8 than in MC/16. With the tuberculate forms the percentages are similar, as are the spinose forms, in each borehole sample; with the exception of 22b and 23b which are rare in MC/16.

Monolete forms: These are not well represented but are commoner in MC/8 than in MC/16.

Winged forms: A variety of form is shown in MC/8 although percentages are less than 2.5 in each case. In number and variety MC/16 shows a paucity of winged forms.

In these samples the overall picture given by the trilete forms is similar in character, although differing in detail. The greatest divergence lies in the proportions of winged forms to the full assemblage for the MC/8 sample shows both variety and numbers which are lacking in the MC/16 sample. This lack is commoner in the lower parts of the sequence yet to be dealt with. It is suggested that these two samples are not the exact equivalents of each other in the two boreholes, but are not widely divergent.

4. LOWER SEAM and THICK SEAM: Basal samples of approximately 2 ft thickness from boreholes MC/8 and MC/16 respectively (Figs 20 and 23, sas (100-110) and (59-62) respectively).

Trilete forms: The dominant form in each sample is 20 with the microreticulate group subdominant in both cases but in differing proportions. Psilate forms are more abundant in MC/16 than in MC/8 while more granulate forms appear to be present in the latter sample. In each case spinose forms are rare, and verrucate forms less rare.

Monolete forms: All groups are represented but only in small quantities.

Winged forms: Between the two samples all forms are recognised but in no case is there more than 1% of any type.

The two samples show the same general features, but in slightly differing proportions. These are the lowest samples inspected and are nearly enough similar to be taken as indicative of similar levels of deposition.

(b) Microfloral assemblages (cont)

(ii) Middle and Lower Seams of MC/8 (Figs 19 and 20)

1. MIDDLE SEAM:

Trilete forms: Apart from the top sample (48-54) already dealt with, the assemblages show no true dominant form but instead show four sub-dominant. The lowest sample (67-72) has in order of importance the forms 13b, 20 and 12a each between 10% and 15% and 22a at slightly less than 10%. Sample (60-66) shows in order, 20, 12a and 13b at between 10% and 17.5% with 22a at over 5%. Sample (55-59) has 12a and 13a at just over 10% with 20 and 22a at about the 10% level. The psilate, verrucate and granulate forms show similar general levels on the graph. The spinose group are not well represented and percentages become lower in the lower samples.

Monolete and winged forms: These are too few in number to base any assumptions on them.

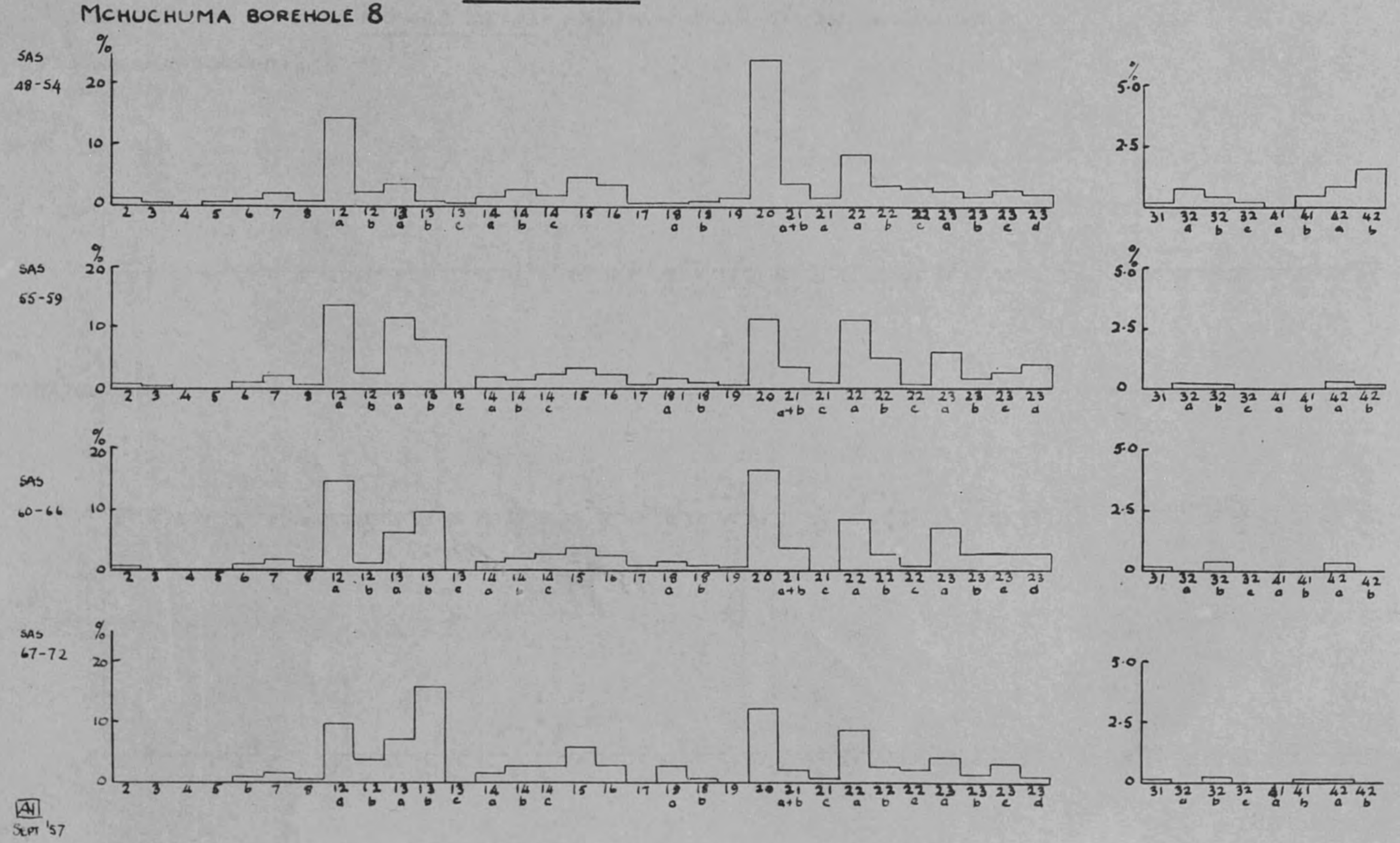
2. LOWER SEAM:

Trilete forms: Samples (90-94) and (95-102) both show No 20 as the dominant spore, and No 13b as the sub-dominant.

Mchuchuma Spore Assemblages

Fig. 19

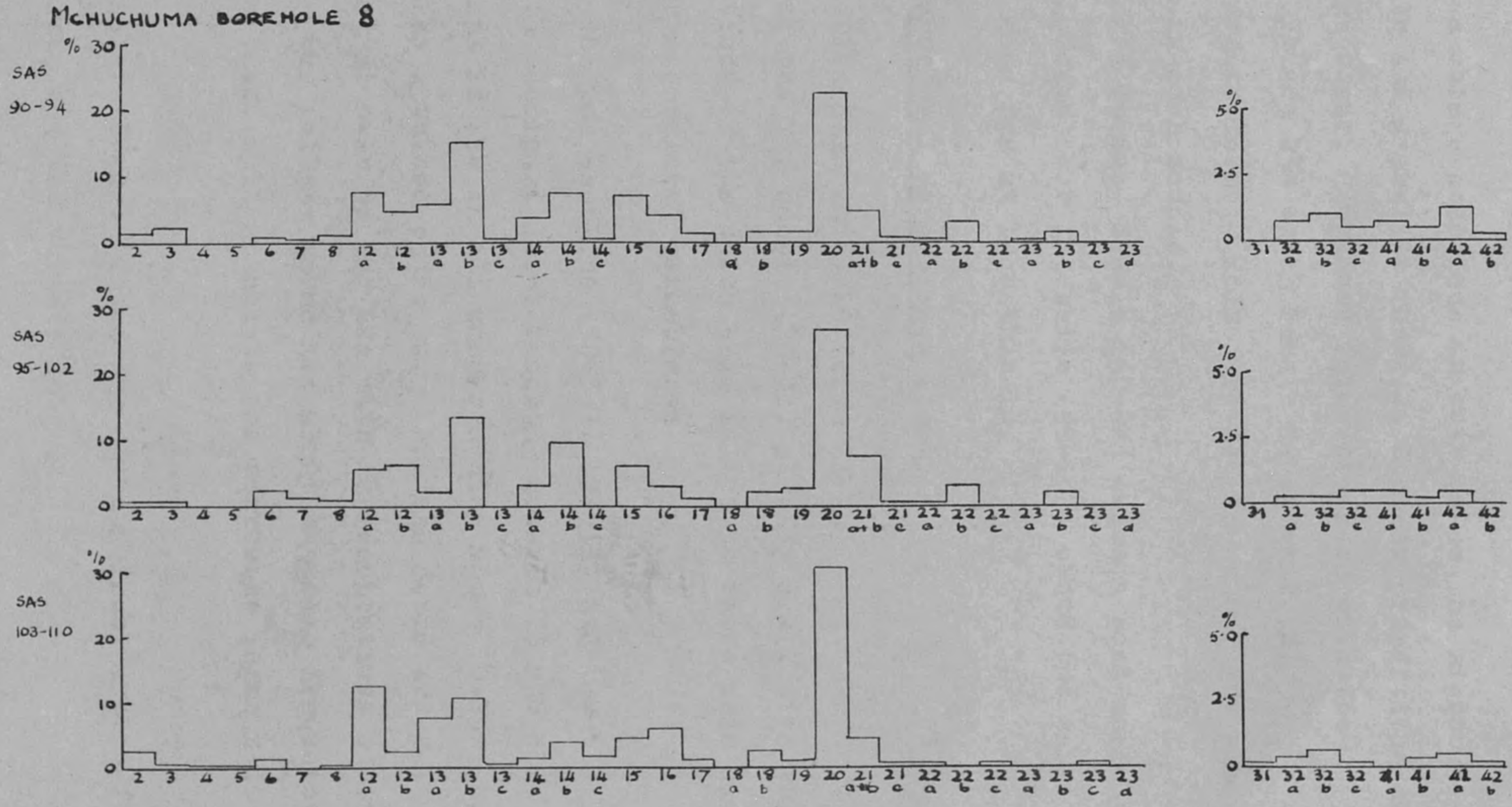
3. Middle Seam - 4 x 2ft. samples - bottom 4ft. not available



MCHUCHUMA SPORE ASSEMBLAGES

FIG. 20

4. LOWER SEAM - 3 x 2 FT. SAMPLES - TOP 2 FT. NOT AVAILABLE



AN SEPT '57

The general assemblage comprises in both cases the microreticulate, psilate and granulate forms. Smaller proportions of verrucate forms occur. Spinose forms are rare with the exception of 22b and 23b which remain at about 2.5%.

Monolete forms: There are few in number but similar in proportion in each sample.

Winged forms: Sample (90-94) shows a good variety having several forms over 1%, while (95-102) shows the same variation but each one at less than 1%.

(b) Microfloral assemblages (cont)

(iii) THICK SEAM in MC/16 (Figs 21-24)

Excluding the top sample (28-31) already dealt with the remaining sections of the thick seam fall into three main divisions on their microfloral assemblages.

Firstly the top sections (32-35), (36-39) and (44-45) in which 13b is the dominant form, reaching between 20 and 30%. The sub-dominant is 12b in all cases reaching about 10-15%, but this may also be attained by No 20. Spinose forms are relatively frequent at over 5% for 22a with representatives of all other forms. The psilate forms are about the same frequency as the spinose ones, with granulate and verrucate forms relatively rare.

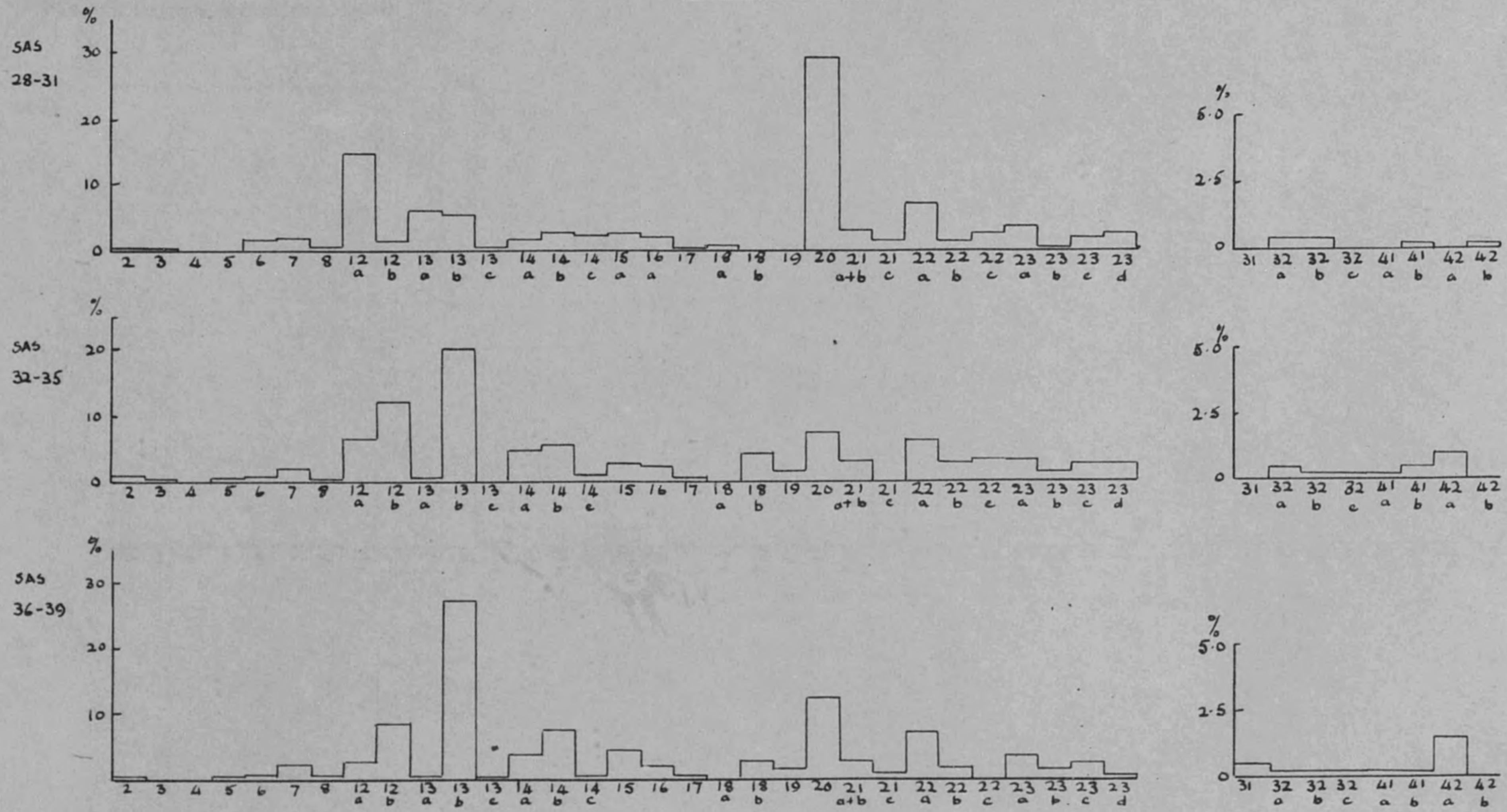
Monolete forms: These are not numerous, except for the spinose group but the variety is good.

MCHUCHUMA SPORE ASSEMBLAGES

FIG 21

MCHUCHUMA BOREHOLE 16

5. THICK SEAM (pt. 1)



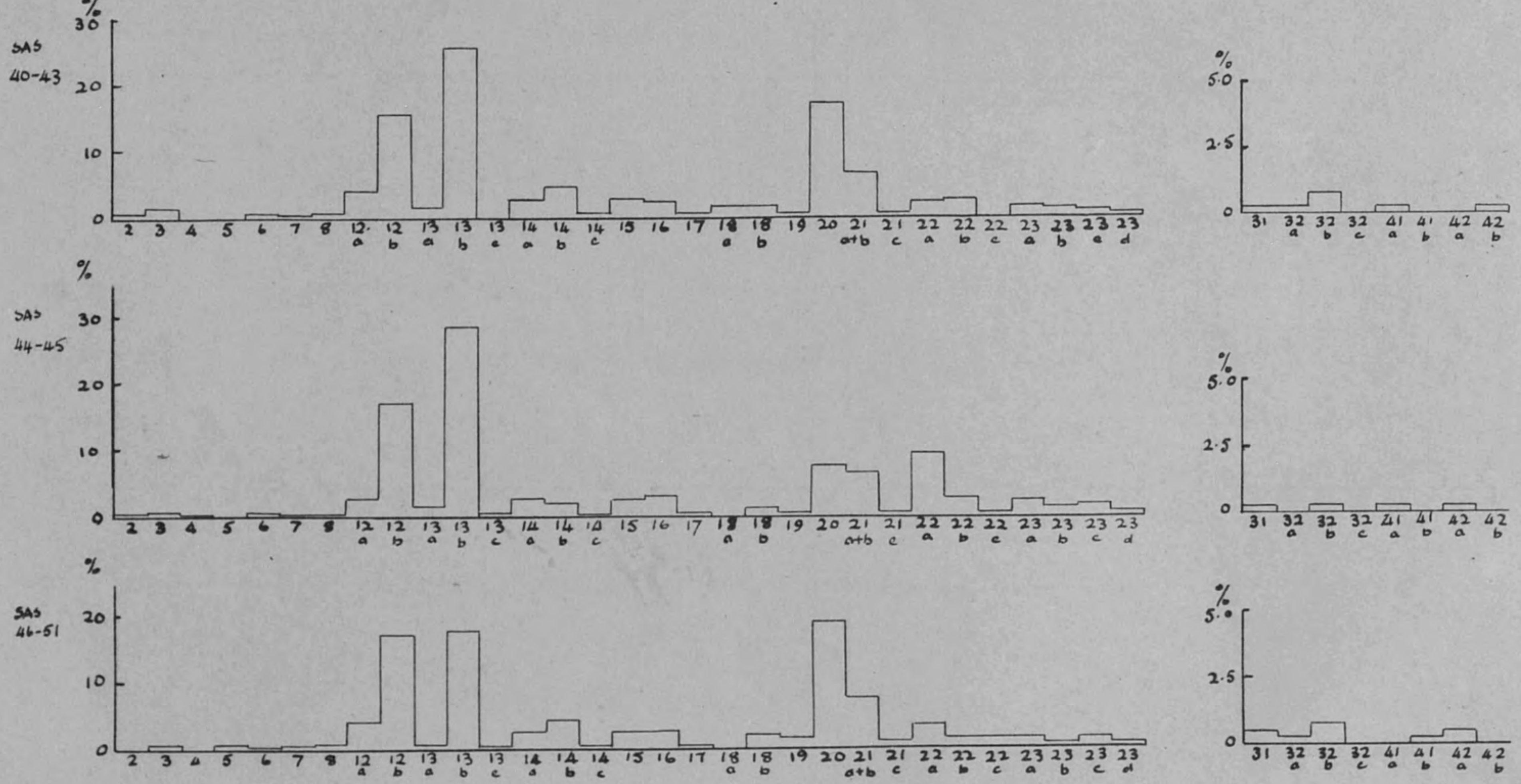
AN
Oct '57

FIG 22.

MCHUCHUMA SPORE ASSEMBLAGES

5. THICK SEAM (Pt. 2)

MCHUCHUMA BOREHOLE 16



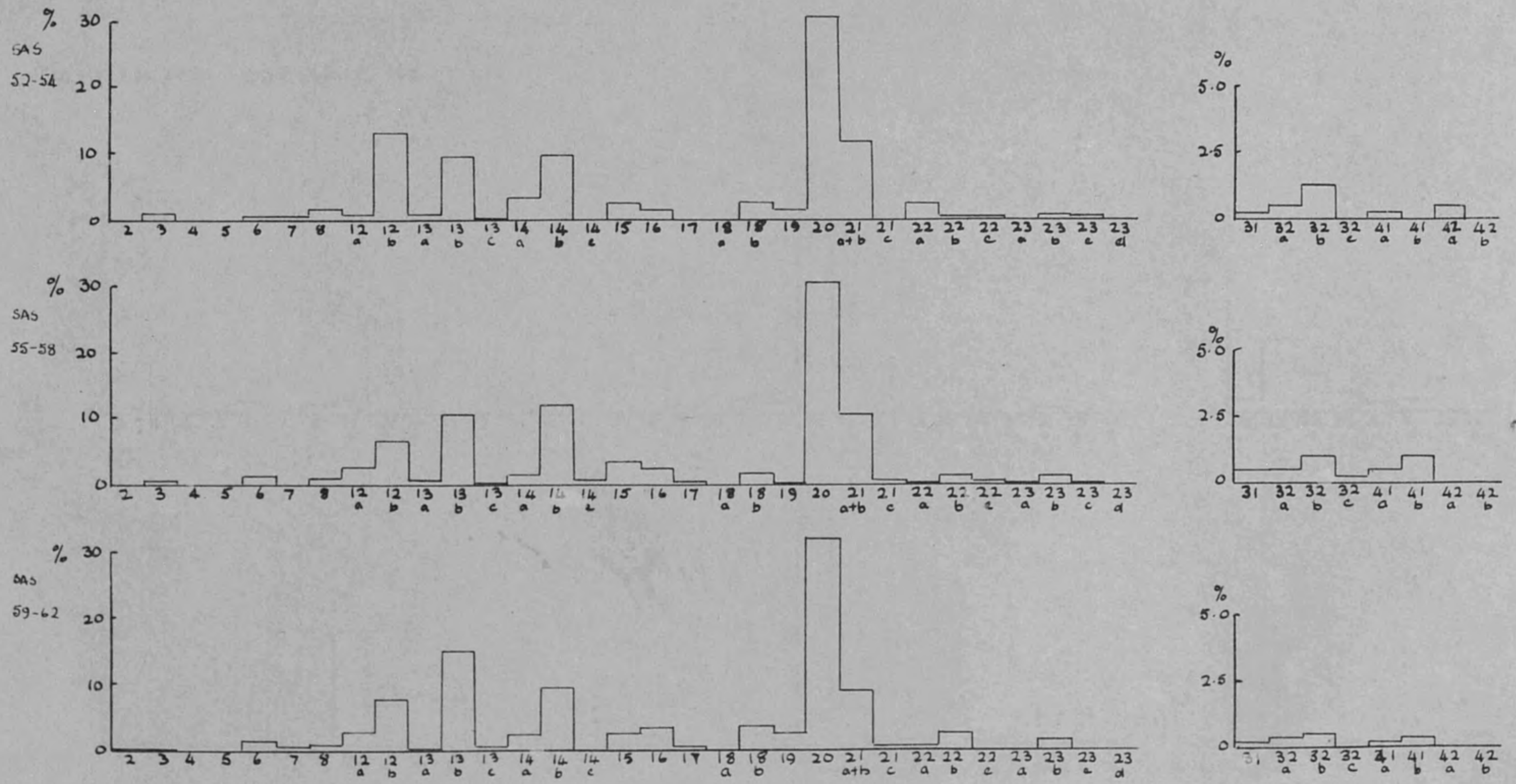
AN
OCT '57

MCHUCHUMA SPORE ASSEMBLAGES

FIG 23

5. THICK SEAM (Pt 3)

MCHUCHUMA BOREHOLE 16



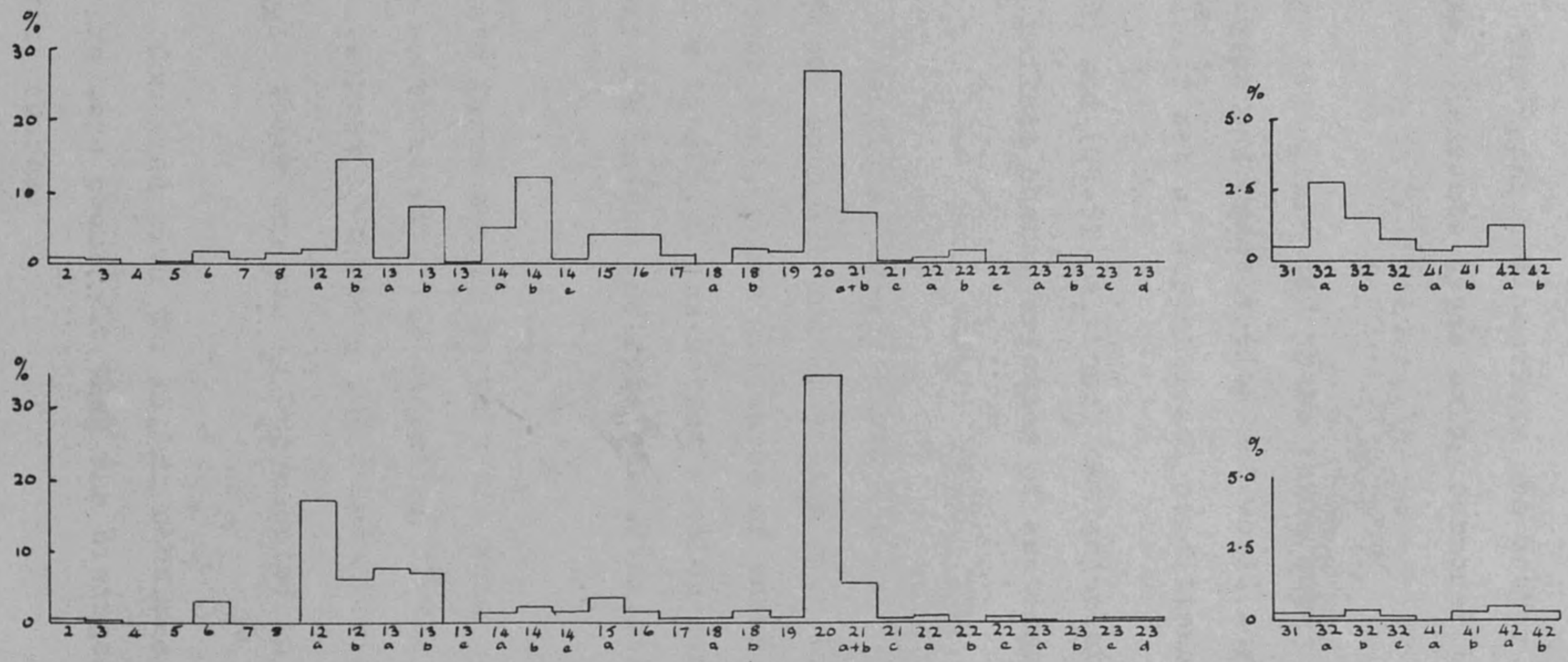
AN
Oct '57

FIG. 24.

MCHUCHUMA SPORE ASSEMBLAGES

5. THICK SEAM (p+4)

MCHUCHUMA BOREHOLE 16



AN
OCT '57

Winged forms: The upper two sections are better represented by these forms, bisaccate types being commoner than the monowinged types.

Taken as a whole the histograms for these three sub-sections are similar in shape and constitution and would suggest a similar flora and a similar set of depositional conditions.

The sections (40-43) and (46-51) although not adjacent, are similar in form, and reflect characteristics of sections both above and below.

Trilete forms - sections (40-43) shows 13b as dominant form at over 20% but both 12b and 20 attain over 15%. Section (46-51) on the other hand, shows all three of these forms at the same level i e 15-20%. The former section reflects the upper sections, whilst the latter reflects characteristics of the lower sections.

The remaining trilete forms are in roughly the same proportions as the upper sections with the exception of the spinose forms, which are reduced in number, but remain varied.

Monolete forms: these are poorly represented in number.

Winged forms: Compared with the higher sections, the single winged forms are more prominent than the biwinged forms, which are relatively scarce.

Sections (52-54), (55-58), (59-62), (63-67) together with the bottom section (68-71) already dealt with, show a distinct change of dominant form - back to No 20 in all cases at about 30% of the total population.

Trilete forms: Section (52-54) still retains form 12b as a sub-dominant form as in the higher sections, but in the lower sections 12b has a tendency to be less important. Form 13b remains at about 10% throughout, but the remaining trilete forms show a marked change in proportion. Throughout these lower sections the psilate forms (except 68-71) are represented by at least 10% of the population, mainly represented by form 14b. The granulate forms become more important at over 2.5% for all samples, and a slight increase is also noted in the verrucate forms. Most marked is the lack of spinose forms, firstly in number in the higher sections, then the scarcity of some forms at the lower levels.

Monolete forms: There is a lack of monolete forms, together with a lack of variety in the lowest sections. The more coarsely ornamented forms are more common.

Winged forms: Genebally there is a greater variety and abundance of the single winged forms although biwinged forms are well represented even in the bottom samples.

(c) Conclusion on Correlation and Microflora in Mchuchuma Coalfield

With the limited amount of material investigated, it has been possible to form a general idea of the correlation of coal measures by microflora in this vicinity. Although detailed work has been carried out on the seams it is felt that not nearly enough background has been achieved to allow more than general conclusions. However, the trends in the composition of sporomorph assemblages have proved of interest.

Seam correlation: consideration of floral assemblages as represented by trilete and winged forms.

The lowest samples investigated were from the base of the lower seam in MC/8 and the base of the Thick Seam in MC/16. From figures 20 and 24, it can be seen that the two levels represented by the histograms of sections (103-110) and (68-71) in MC/8 and MC/16 respectively show a marked similarity in spore population in both trilete and winged groups. Minor details differ, but the general shape and form of the histograms are similar enough to warrant the conclusion that these two levels of coal were deposited at about the same time, or at least under similar conditions - due to proximity of the boreholes this amounts to the same thing - and it is therefore possible to utilise this level as a datum level for both seam correlation and, a consideration of the flora itself. It is of course, a well defined stratigraphical level.

If the Thick Seam of MC/16 is to be equivalent in time and hence deposition, to the Middle and Lower Seams of MC/8 then a total of 19 feet 3 inches of coal in MC/16 must be equivalent to 31 feet of strata including 11 feet 5 inches of intervening sandstone between the two seams of MC/8. (i e 19 feet 7 inches coal, slightly more than the Thick Seam in MC/16) Similarly between the level of the Intermediate Seam in MC/16 and the top of the Thick Seam 36 feet 5 inches of strata are found, while between the same (?) seam and Middle Seam of MC/8 only 19 feet 6 inches of strata were laid down. For sediments which can accumulate as quickly as sandstones this second difference is less significant than the discrepancy in time which appears in comparing the lower coal seams. If the strata above the Intermediate Seam are considered MC/16 shows 30 feet of strata below the Top Seam, and MC/8 27 feet 7 inches - i e no significant difference.

The basal sections of the Top Economic Seam in each case were considered in a previous paragraph - ref. Figure 17. As in the case of the lowest sections of the Lower and Thick Seams, the trilete and winged forms show an approximately similar form in the histogram. These levels are therefore assumed to be of the same, or similar age and depositional conditions.

With the Intermediate Seam only the one section from MC/16 was available but it is distinct when compared with either the basal section of the Top Seam or the top section of the Middle Seam of MC/8. It is therefore, reasonable to assume that this seam corresponds to the unsampled seam of MC/8 lying between the Top and Middle Economic Seams.

These assumptions therefore leave approximately the same thickness of strata in each of the two boreholes, between the base of the Intermediate Seam and the base of the Lower and Thick Seams respectively; in either case there is about 19½ feet of coal and 31 feet of other strata, but in MC/8 this is divided into 2 seams and 2 bands of strata, while in MC/16 it is in only one thick band of each. The fact that the sections studied from the top of the Middle and Thick Seams did not appear to procuce similar histograms of spore populations further suggests that the two seams of MC/8 although apparently equivalent to the Thick Seams of MC/16 for mining purposes are not exactly contemporaneous in deposition for stratigraphical purposes.

In the paragraphs on microfloral assemblages, the Thick Seam of MC/16 was divided into certain natural parts. These will now be considered in comparison with the available sections of the Lower and Middle Seams of MC/8 and the analytical information given at the beginning of this section.

The Lower Seam of MC/8 (Figure 20), showed a general sporomorph assemblage in which the tuberculate form No 20 was dominant, the microreticulate forms were a subdominant group, and psilate and granulate forms made up a constant background flora. Spinose forms were rarer than in higher assemblages in the sequence. The equivalent of this seam (together with the 2 feet at the top not studied) is to be found in the lowermost 5 sections of the Thick Seam in MC/16 (Figures 23-24). These sections show the same dominance of the tuberculate form No 20, with the microreticulate group sub-dominant. The same sort of proportions of granulate ones is evident, and the same lack of spinose forms. The psilate forms are more prominent in MC/16 than in MC/8, and together with the Winged forms, show that in all probability these 5 sections representing 9 feet 8 inches coal of relatively low specific gravity are the equivalent of the full 8 feet 5 inches of the Lower Seam.

In figure 22 - the histograms of the sections of the Thick Seam differ markedly from either the Lower Seam, or available sections of the Middle Seam of MC/8. Sections (46-51) and (40-43) differ slightly from (44-45). This may be able to be explained by a difference in analysis for the two former show a higher specific gravity than the latter, and hence may be represented by a slightly different flora. The most notable differences are more spinose forms in the central section, and fewer psilate and winged forms, associated with a band of relatively low specific gravity.

Comparing figures 19 and 21 there appears to be little similarity in the histograms of the boreholes - although general tendencies are similar between the four sections of the Middle Seam of MC/8 and the two uppermost sections of the Thick Seam of MC/16 i e (28-31), and (32-35). The general assemblage consists, in the main of a dominant tuberculate form No 20, with the microreticulate forms well represented. In these six sections psilate and granulate forms, do not play any great role - although the MC/16 sections show a higher proportion of psilate forms than in MC/8. The spinose forms are much more abundant than in lower sections, but in this factor the sections (28-31) and (32-35) of MC/16 correspond more to the sections (60-66) and (67-72) of the Middle Seam - i.e. towards the middle of the seam not the top. This fact is supported by the proportions of winged forms which are sparse, and again tend to suggest that the top of the Thick Seam MC/16 is contemporaneous with the Middle of the Middle Seam in MC/8. The actual level suggested for the placing of the top of the Thick Seam of MC/16 is at section (60-66) in MC/8. This is not as well shown in figures 19 and 20 as in the seam sequence of Figures 25 and 26. It could then be assumed that the remaining portion of the Middle Seam of MC/8 below section (60-66) (i e 3 samples) would be the equivalent in time to samples (32-35) and (36-39) from MC/16 - the break being put at this level because of the slight change in flora associated with the higher specific gravity of (40-43). This gives the top 4 feet 10 inches of the Thick Seam as equivalent to all but the top 3 feet 9 inches of the Middle Seam of MC/8.

The remaining 4 feet 7 inches of coal in the middle of the Thick Seam have no equivalent coal strata in MC/8 probably being deposited simultaneously with the intervening sandstones of that borehole sequence. The three sections as set out above cannot be equated accurately due to the assumptions having to be made on the base of the Middle Seam and the top of the Lower Seam respectively. But the slight differences in flora, and the marked differences in specific gravity of these adjacent sections, and hence chemical analysis, do point to the fact that the coal deposition in the thick seam of MC/16 at the time the sandbank (?) was forming between the Lower and Middle Seams of MC/8, was not entirely unaffected by the instability of conditions. It is relevant to point out here that the two periods of coal deposition represented by the Middle and Lower seams of MC/8 produced coals of low specific gravity and high carbon content more consistently than the equivalent portions of the Thick Seam in MC/16.

The foregoing paragraphs indicate that for general correlative purposes, the use of sporomorph assemblages can provide reliable information, which can be interpreted sufficiently for mining purposes - i e general seam correlations. From the economic aspect, the sporomorph assemblages can provide useful information, but the area covered by this study is too small to draw any further conclusions. More boreholes, with wider spacing would have to be studied before drawing any far reaching conclusions as to the value of the sporomorph assemblages in the Ruhuhu coalfields.

(6) Development of Microflora of Ruhuhu Coalfields

In the preceding paragraphs, seam correlations by microspore content has been discussed - i e the economic side of the results. From the stratigraphical point of view the study has also achieved some interesting results, with reference to the development of the microflora of the coalfields.

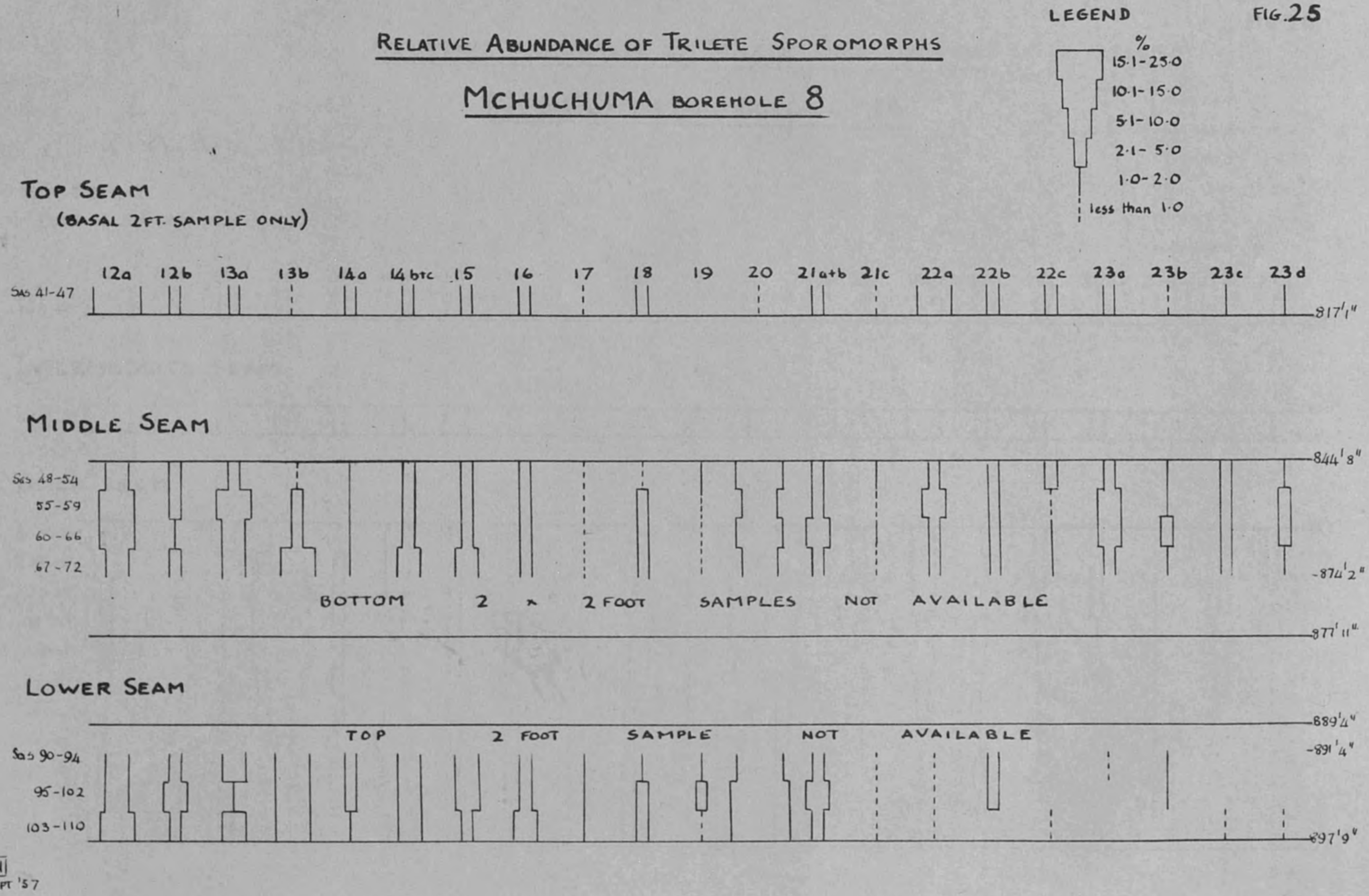
Before discussing the relative abundance of the various sporomorphs, at different horizons, it is as well to draw attention again to the qualitative nature of all the data. The fact that a sporomorph may comprise up to 25% of the flora at a low horizon, and only about 10% at a higher level need not necessarily imply that the plant which produced it diminished in numbers. Where a small variety of sporomorphs are present the proportions of each are naturally greater than a case where a great variety of forms are present. This is the situation in the Ruhuhu coals, where few forms are present at the earliest stages of coal deposition, and a larger number of forms - in small proportions are present at the higher levels.

(a) The Coal Microflora of the Mchuchuma Samples (Figs. 25 + 26).

At the lowest levels studied i e base of the Thick Seam and base of the Lower Seam the microflora already shows practically all the forms encountered in the study, but several forms are fairly numerous, whereas other groups are practically non-existent. The lowest assemblages consist of finely ornamented forms, in which all microreticulate forms are well represented. Psilate forms are fairly well represented. The coarsely ornamented tuberculate form is a dominant feature at this early level, whereas the small spinose forms are relatively rare, if not absent. Granulate forms are present, but these appear constant throughout the sequence both in proportions and form. Winged spores are represented by all varieties, although more are abundant.

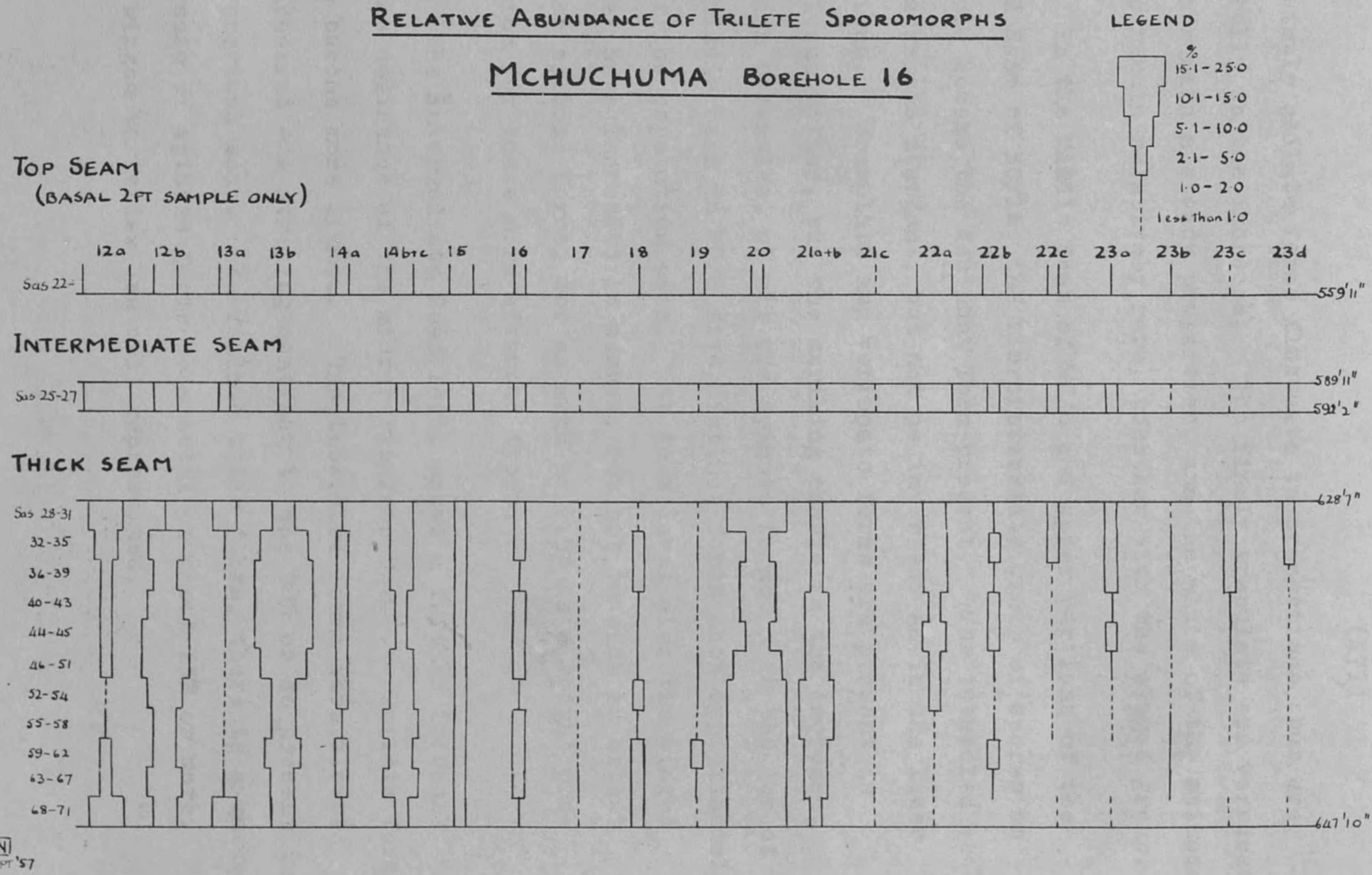
Throughout the lower sections of the Thick Seam of MC/16, and the Lower Seam of MC/8 the microreticulate forms continue in abundance, with the tubercled forms as the dominant type.

FIG. 25



RELATIVE ABUNDANCE OF TRILETE SPOROMORPHS
MCHUCHUMA BOREHOLE 8
LEGEND
%
15·1-25·0
10·1-15·0
5·1-10·0
2·1-5·0
1·0-2·0
less than 1·0
TOP SEAM
(BASAL 2FT. SAMPLE ONLY)
12a 12b 13a 13b 14a 14b+c 15 16 17 18 19 20 21a+b 21c 22a 22b 22c 23a 23b 23c 23d
Sas 41-47
817'1"
MIDDLE SEAM
Sas 48-54
55-59
60-66
67-72
844'8"
874'2"
BOTTOM 2 × 2 FOOT SAMPLES NOT AVAILABLE
877'11"
LOWER SEAM
889'4"
TOP 2 FOOT SAMPLE NOT AVAILABLE
Sas 90-94
95-102
103-110
891'4"
897'9"
ANJ
SEPT '57

FIG 26.


RELATIVE ABUNDANCE OF TRILETE SPOROMORPHS
MCHUCHUMA BOREHOLE 16
LEGEND
%
15·1 - 25·0
10·1 - 15·0
5·1 - 10·0
2·1 - 5·0
1·0 - 2·0
less than 1·0
TOP SEAM
(BASAL 2FT SAMPLE ONLY)
12a
12b
13a
13b
14a
14b+c
15
16
17
18
19
20
21a+b
21c
22a
22b
22c
23a
23b
23c
23d
Sas 22-
559'11"
INTERMEDIATE SEAM
Sas 25-27
589'11"
592'2"
THICK SEAM
Sas 28-31
32-35
36-39
40-43
44-45
46-51
52-54
55-58
59-62
63-67
68-71
628'7"
647'10"
AN
SEPT '57

The simple psilate forms fluctuate in proportions, but are generally on the increase, The finely granulate and verrucate forms remain a steady proportion, and the whole of the spinose group remain relatively rare, together with the winged group.

In the Middle Seam of MC/8 and upper portions of the Thick Seam of MC/16, the microreticulate group of spores as a whole become the dominant form present. The tubercled forms remain abundant, but not as important as in the lower sections. Granulate and verrucate forms are present in small quantities, but the striking change is the increase, in both boreholes, of all the spinose forms. At the top of the Middle Seam in MC/8 five distinct forms show approximately 5% of the population each. At this level also the winged spores have increased in number, but not to such an extent as the spinose forms, for as much as 2.5% is a 'high' proportion for these more advanced types.

The Intermediate Seam level shows a further increase in the dominance of the microreticulate forms. Psilate forms have become more common. The tubercled forms have almost disappeared - a striking contrast to the 20% or so present in the previous seam. To replace these forms, there is a marked increase of spinose forms to a total of about 25% or more. The winged varieties are well represented.

The Top Seam in each borehole is again noteworthy for the abundance of certain of the microreticulate forms, the whole group being dominant. Again the spinose forms are well represented, being almost as abundant as the micro-reticulate forms. With the exception of the two groups of spores already mentioned, all other sporomorphs at the base of the Top Seam are in small quantities only, and apparently play only a minor part of the total flora.

The trends shown by the microflora of the seams in the coal sandstone series of Mchuchuma can be summarised as follows. There is a general increase in numbers of types from the earlier sediments to the top, but some forms dominating the flora at the beginning of the main coal de-position became less important as the flora develops, whilst certain other forms take over the more important roles. Of the trilete forms, the group having tuberculate ornamentation is generally on the decrease, or at least becomes less import-ant as deposition continues. On the increase is the micro-reticulate ornamentation group, which is well represented though not dominant at the base of the coal deposits. The spinose ornamentation group, which is hardly represented in the earliest coals, rises to subdominance by the top of the coal sandstone series. These three groups of sporomorphs show the general trends and individual forms within the groups show the trends even more clearly e g No 20, and

No 21a and b in the tubercled group, Nos 12a, 12b and 13b in the microreticulate group, and Nos 22a and 22b from among the spinose group. To a minor extent the psilate group of sporomorphs shows a fluctuation in numbers, but not pronounced enough to be a distinct trend. Of the remaining forms both the granulate and verrucate groups contribute little to the actual flora, except a steady background constituent. The winged groups are notable by their presence, and by the fact that all members of the flora are recognisable, even from near the base of the coals. With this group however, a great deal more work would have to be done on the small though adequate numbers, before trends could be discussed.

(b) The Coal Microflora of the Mbuyura Samples (Figures 13, 14)

The samples from the Mbuyura Coalfield have not been subjected to such a detailed investigation as those from the Mchuchuma Coalfield, for the three samples only have been investigated, and no adjacent sections have been studied. However, the three levels considered have distinct characteristics and could be considered a continuation of the previous section, although some allowance must be made for the hiatus between the topmost samples considered in Mchuchuma and the samples from Mbuyura.

In the uppermost samples of the Mbuyura sequence, the two dominant ornamentation groups are ~~were~~ the microreticulate and the spinose groups. Sample MB/6 contains abundant representatives of both these groups, but the microreticulate forms, if continuing a trend, are on the decline, while the spinose forms are just about steady. The fluctuating psilate group has here sprung to dominance in its triangular forms, but the discoidal form is also abundant. Sample MB/3 returns to a predominance of microreticulate forms, which decreases again by the time MB/1 is reached. Relatively few spinose forms are present in MB/3, so that the increasing of this floral constituent has been curtailed, but it gains full dominance in the top sample - MB/1. The psilate group remains an important group, compared with its proportions as present in the Mchuchuma samples. The background flora is still made up of the granulate, verrucate and tuberculate forms in varying proportions - of which the tubercled forms appear to be diminishing still further, with the granulate forms showing a reverse tendency.

The winged group were not investigated as fully in the early Mbuyura samples, as in the later Mchuchuma borehole cores. Mono-winged forms are apparently more abundant than the bi-winged forms, which are few in number, and being scarce could not be subdivided into types.

Throughout the whole sequence, monolete forms have been present - in both Mbuyura and Mchuchuma samples - usually reflecting the dominance or scarcity shown by their corresponding trilete forms. This impression may be due to difficulty in identification or it may be a true state of affairs, where the proportion of sporomorphs produced in bilaterally symmetrical tetrads depends upon the proportion produced by tetrahedral tetrads . i e not necessarily separate species. But the one unique form - No 8a, appears throughout the full sequence - in minute numbers at first, but when established retaining a constant percentage of the flora.

S E C T I O N   III

S U M M A R Y   AND   C O N C L U S I O N S

SECTION III : SUMMARY AND CONCLUSIONS

Despite the poor promise of African coals for microspore study (see Rillett) the Ruhuhu coals which have been examined here have provided ample material for study of both a palaeontological and stratigraphical nature. The samples used have been few but carefully selected, and thoroughly investigated. At the outset it was felt that the study might be a biased one, in which palaeontological data would be small, and the whole investigation would hinge on the correlative value of a few forms influenced by the research of other workers. On the contrary, the palaeontological side has involved much study of types, produced enough material to give preliminary diagnoses of spores, and warranted a detailed investigation of the method of classification already in use, and the place of the East African sporomorphs within these systems. Originally, it was envisaged that several borehole sequences might be studied in detail, but time has only allowed the study of 2 sequences in the detail required.

(1) Palaeontology

It has been possible to distinguish and describe over 40 spore types from the Ruhuhu material, in this preliminary study. Further types may come to light with more concentrated investigation. On the whole, the sporomorphs are simple in form, their shapes varying from flattened tetrahedra and discs to bilaterally symmetrical forms. All gradations can be found between tetrahedral forms having concave sides to those having convex ones, with varying degrees of angularity at the apices. The smallest of the simple forms is less than 15 microns in diameter, while the largest approach 100 microns. The ornamentation of the spore coat is of a simple nature, in the finer ranges it is dominated by the trilete or monolete suture, whereas the coarser ornaments mark the suture. The range of ornament is not great, there being only one form which has combined elements (i e the broad based spine of 22 and 23b). The remaining sporomorphs show microreticulate ornament of less than 3 microns, or granulae, verrucae, tuberculae and spinae most of which are less than 3 microns in any one or all dimensions. From the study made of spores of Bryophyta and Pteridophyta by Knox it would be reasonable to assume that the simple sporomorphs of the Ruhuhu coals represent a lowly flora, with an admixture of some more advanced forms represented by the more complex winged forms. This is an important observation, as the macro-floral remains have only yielded fronds of Glossopteris, Gangamopteris and Rhexoxylon, and a few Calamites fragments. Hence it is safe to say, that a fairly extensive though lowly, flora existed in the hinterland of the lagoons where the coals were accumulating.

The more complex of the sporomorphs are the monosaccate forms (pre-pollen?) and the bisaccate forms together with the unusual oval striate form. This latter is recorded by Balme and Hennelly as having paired air sacs, and on this basis should be discussed with the primitive pollen group. But as no such features have been detected on the Ruhuhu specimens, it is preferable to leave them in a separate group. The Monosaccate group does not seem to be as well represented in the Ruhuhu coals, as in those of other Permian coals, nor for that matter, as in the earlier American Carboniferous coals. This may however be an environmental factor, as the coals were not formed in situ. The bisaccate group is also not well represented, but 4 or 5 distinct 'species' can be recognised. They are related to the <u>Pityosporites</u> type of pollen which occurs in the Permian coal measures, but no evidence as to their origin or affinities is offered. It is believed by other authors that the pollen - coniferous in type - was produced by an advanced gymnosperm, and that the most probable parent was <u>Glossopteris</u>, with which it is normally in association. The advanced spores and pollen, although in smaller quantities than the simple forms are an important factor in the flora, for they must have been produced by a relatively well advanced plant community.

When comparing the flora of the Ruhuhu coals with those of any other area, the smallness of the sequence of coals must be taken into account. In the whole of the series under consideration two separate sequences have been used, the total amount of strata covered being not more than 150 feet. This compares unfavourably with the Carboniferous measures investigated for their spore content which may run into thousands of feet, and even the Permian measures from India and Australia cover several hundreds of feet of strata.

(2) <u>Seam Correlation</u>

In the seoond part of the Investigation the economic potentialities of the sporomorphs described in the first part were explored. This aspect took 3 forms:-

(1) The inspection, as a preliminary measure, of samples from three different levels in the Mbuyura coal sequence. Although only separated by a few feet of strata the three two foot representative samples yielded three fairly distinctive types of microflora. No comparisons were able to be made with another coal section, so that no estimate of the reliability of the assemblages could be made.

(2) The comparison of selected horizons, believed to be of similar age and probably constitution, from two separate localities - i e adjacent boreholes in the Mchuchuma coalfield.

Of the four selected horizons, one had no counterpart in the other borehole, but two namely the base of the Top Seams,and the base of the Lower and Thick Seams respectively were found to resemble each other, and were therefore presumed to be contemporaneous. The fourth sample pair - top of Middle Seam and top of Thick Seam did not resemble each other in certain features, and were assumed to be of slightly different ages. However, the full significance of these similarities and differences cannot be assessed until more borehole cores have been studies in detail.

(3) The detailed study of the sequence of microfloras in a series of seams, and its comparison with the seams of the adjacent borehole. It was again possible to compare the sporomorph assemblages from certain sections in one borehole, with those of the other, but in places distinct differences were noticeable. For instance there was no comparative section in the Middle or Lower Seam of MC/8 to the Middle Sections of the Thick Seam of MC/16. Similarly the top of the Middle Seam of MC/8 did not compare with the top sections of the Thick Seam of MC/16. But in both borehole sequences the same sort of microfloral sequence could be traced from the bottom to the top of the coal series studied, indicating that regardless of local differences of sedimentation, the area was one of consistent conditions.

For mining purposes, the result of correlation attempts between sections of the seams it would be sufficient to say that the Middle and Lower Seams of MC/8 correspond to the Thick Seam of MC/16. But further detailed work would be necessary to link up these borehole sequences with the other boreholes in the coalfield. This might take the form of (2) above, in that 'key' horizons only need be studied in the first place, to give a broad correlation.

During the course of the Investigation it was found necessary to devote a considerable amount of attention to the problems of classification of sporomorphs in general. In the initial stages it was felt that only the Permian schematic classification would need to be studied to give the basis for classifying spores from the Ruhuhu coals. But it was eventually decided that a full survey of the classificatory methods used by as many research workers as possible, was necessary before attempting to place the Ruhuhu spores into any system whatever. This has all been dealt with in the Introductory Survey of classification - but only those aspects dealing with micro- and iso-spores have been touched upon.

It is felt that, besides the original part of the thesis as contained in the descriptions and correlative use of the sporomorphs a substantial amount of new work has been included in the paragraphs on classification especially in the comparative charts 1-8. For it is hoped that in this part the work of many authors has been summarised into an easily comprehended and comparative form. The survey covers classifications from Raistrick to the present Potonie and Kremp work - laid out in a similar form for comparing and contrasting each with the others. The schematic classification used for the Ruhuhu coals although newly created for this work, is not completely divorced from previous authors' work, nor from the subsequent re-classifying of all Palaeozoic aporomorphs by Potonie and Kremp. The whole section on classification and charts is intended as a simplified guide to the synonymy of the Ruhuhu spores, with those of other authors - especially of the Australian Permian spores, and the apparently complex Linnaean system of Potonie and Kremp, with which it is possible to compare the 'new' scheme in the diagrammatic form more easily than might have been anticipated from descriptions alone.

Briefly, the Investigation has shown that sporomorphs are present in sufficient quantities in the Ruhuhu coals to be identified and described: they are sufficiently well organised into microfloral assemblages and sequences to be of both economic and stratigraphical interest to Permian spore workers. Enough material has been studied to warrant a thorough study of classificatory methods, and further work could prove fruitful in both the Palaeontological and Stratigraphical aspects.

B I B L I O G R A P H Y

BIBLIOGRAPHY

COLONIAL DEVELOPMENT CORPORATION: Tanganyika Coalfields Investigation - Final Report, 1956.

BALME, B.E.: "The Principal Microspores of the Permian Coals of Collie." Bull.Geol.Surv.W.Austr. 105 pt.1. Perth 1952. pp. 164-201.

BALME, B.E. and J.P. HENNELLY: Bisaccate sporomorphs from Australian Permian Coals. Australian Jour. of Botany. Vol.3, No 1. 1955, pp. 89-98.

BORNHARDT, W.: Zur Oberflachengestaltung und Geologie Deutsch-Ostafrikas. 1900. (Berlin?).

COUPER, R.A.: Nomenclature of Fossil Spores and Pollen Grains. VIIIe Congres Internationale de Botanique, Sect.2. 1954, p.1.

DULHUNTY, J.A.: Principal Microspore Types in Permian Coals of New South Wales. Proc.Lin.Soc.N.S.W., Vol. lxx, pt. 3-4, 1945.

DULHUNTY, J.A.: Distribution of Microspore types in the New South Wales Permian Coalfields. Proc.Lin.Soc.N.S.W., Vol. lxxi, pts. 5-6, 1946.

BIBLIOGRAPHY

COLONIAL DEVELOPMENT CORPORATION: Tanganyika Coalfields Investigation - Final Report, 1956.

BALME, B.E.: "The Principal Microspores of the Permian Coals of Collie." Bull.Geol.Surv.W.Austr. 105 pt.1. Perth 1952. pp. 164-201.

BALME, B.E. and J.F. HENNELLY: Bisaccate sporomorphs from Australian Permian Coals. Australian Jour. of Botany. Vol.3, No 1. 1955, pp. 89-98.

BORNHARDT, W.: Zur Oberfrashergestattung und Geologie Deutsch-Ostafrikas. 1900. (Berlin?).

COUPER, R.A.: Nomenclature of Fossil Spores and Pollen Grains. VIIIe Congres Internationale de Botanique, Sect.2. 1954, p.1.

DULHUNTY, J.A.: Principal Microspore Types in Permian Coals of New South Wales. Proc.Lin.Soc.N.S.W., Vol. lxx, pt. 3-4, 1945.

DULHUNTY, J.A.: Distribution of Microspore types in the New South Wales Permian Coalfields. Proc.Lin.Soc.N.S.W., Vol. lxxi, pts. 5-6, 1946.

DULHUNTY, J.A. & R.: Notes on Microspore Types in Tasmanian Permian Coals. Proc.Lin.Soc.N.S.W., Vol. lxxiv, pts. 3-4, 1949.

ERDTMAN, G.: Suggestions for classification of fossil and recent pollen grains and spores. Svensk.Bot.Tidskr., Vol. 4', No 1, pp. 104-114, 1947.

GHOSH, A.K. and J.SEN: A study of the microfossils and the correlation of some productive coal seams in the Raniganj Coalfield, Bengal, India. Trans.Min.Geol. and Met.Inst. India, Vol. 43, No 2, July 1948.

GODWIN, H.: Pollen Analysis. An outline of the problems and potentialities of the method. New Phytologist, 33, p. 289, 1934.

GOSWANI, S.K.: Microfossils from coals from the Lower Gondwanas of Rewa India (Vindhya Pradesh). Jour.Sci.Research, Benares Hindu University, Vol. 1, 1950-51, p. 153.

GOSWANI, S.K.: Microfossils from Coals from the South Rewa Godwana Basin Dharpuri (Bihar). Jour.Sci.Research, Benares Hindu University, Vol. 2, 1951-52, P. 190.

HITCHEN, C.S.: Coal Resources of the Colonial Empire. Times Review of the Colonies, Autumn 1953.

de JERSEY, N.J.: Microspore types in some Queensland Permian coals. University of Queensland Papers. Dept.Geol. Vol. 3(NS), No 5, pp. 1-12, 1946.

de JERSEY, N.J.: Principal Microspores in the Ipswich Coals. University of Queensland Papers. Dept.Geol., Vol.3 (NS), No 9, 1949.

de JERSEY, N.J.: Microspore Correlation in the Burrum Coalfield. Queensland Govt. Mining Jour, 52, pp. 780-9, Oct. 1951.

KNOX, E.M.: The spores of Pteridophyta with observations on microspores in coals of Carboniferous Age. Trans.Bot.Soc. Edin., Vol. xxxii, p. 438 et seq., 1938.

KNOX, E.M.: The Spores of Bryophyta compared with those of Carboniferous Age. Trans.Bot.Soc.Edin., Vol. xxxii, p. 477 et seq., 1939.

KNOX, E.M.: Microspores and their Biological significance. Trans.Bot.Soc.Edin., Vol. 35, p. 109, 1949.

KNOX, E.M.: The Spores of Lycopodium, Phylloglossum, Selaginella and Isoetes and their value in the study of spores of Palaeozoic Age. Trans.Bot.Soc.Edin., Vol. 35, p. 211 et seq., 1950.

KNOX, E.M.: Palynology and Coal Stratigraphy. Trans.Edin.Geol.Soc., Vol. xv, pp. 221-233, 1952.

KOSANKE, R.M.: Plant Microfossils in the Correlation of Coal Beds. Jour.Geol., Vol. 55, p. 280, 1947.

KOSANKE, R.M.: Pennsylvanian spores of Illinois and their use in correlation. Bulletin Ill.Geol.Surv., No 74, 1950.

LUBER, A.A.: Spores and Pollen from the coals of the Permian of U.S.S.R. Problems of Sov.Geol., Vol. VII, No 2, p. 151, 1938.

LUBER, A.A.: Methods for correlating coal seams of Palaeozoic Basins according to spores. 17th Int.Geol.Congr. Moscow (Abstracts), 1937.

LUBER, A.A.: Correlation by means of spores of the coal bearing Upper Palaeozoic beds of the Kuznetsk and Minussinsk basins. Bull.Acad.Sci.U.S.S.R., Serie 7A, pt. 2, No 6 (Eng. summary), pp. 88-104, 1939.

McKINLEY, A.C.M.: Geology of the Kitewaka-Mchuchuma Coalfield. Bull. No 21, Tanganyika Geol. Survey Dept., 1954.

MAZURCZAK, L.: Notes on the Ruhuhu Coalfield (Southern Province, Tanganyika Territory) 5th E.African Inter Territorial Geol. Conference, 1952.

MEHTA, K.P.: Microfossils from a Coal Shale from the Pali beds of the South Rewa Gondwana Basin. Proc.Nat.Acad.Sci. India, Vol. 14, p. 125, 1944.

MOORE, L.R.: On the spores of some Carboniferous plants and their development. Q.J.G.S., Vol. CII, p. 251, 1946.

NAUMOVA, S.N.: The spores and pollens of the coals of U.S.S.R. Rec. 17th Int.Geol.Congress, Moscow, pp.353-364, 1937.

PANT, D.D.: On the occurrence of Pityosporites Seward in a Lower Gondwana tillite from Australia, and its possible relationship to Glossopteris. Proc. 36th Ind.Sci.Cong., pt. 4, 1949.

PANT, D.D.: Suggestions for Classification and Nomenclature of Fossil Spores and Pollen Grains. Botanical Review, Vol. 20, No 1, pp. 33-60, 1954.

PANT, D.D.: On two new disaccate spores from the Bacchus Marsh tillite, Victoria (Australia). Annals & Mag.Nat.Hist. Vol. 8, Ser. 12, No 94, pp. 757-764, 1955.

POTONIE, R.: Zur Morphologie und morphologischen Nomenklatur der Sporites H. Potonie 1893. Palaeont.Z. 25 3/4 pp. 143-154, Stuttgart 1952.

POTONIE, R.: Zur Palaeontologie der Sporites. Palaeont.Z., 27 1/2, pp. 32-36, Stuttgart 1953.

POTONIE, R.: Stellung der palaeozoischen Sporengattungen im naturlichen System. Palaeont.Z., 28, 3/4, pp. 103-139, Stuttgart 1954.

POTONIE, R. and W. KLAUS: Einige Sporengattungen des alpinum Salzgebirges. Geol.Ib.Band 68, pp. 517-546, Hanover 1954.

POTONIE, R. and G. KREMP: Die Gattungen der palaeozoischen sporae dispersae und ihre Stratigraphie. Geol.Jb. Band 69, pp. 111-194, Hanover 1954.

POTONIE, R. and G. KREMP: Die Sporae dispersae des Ruhrkarbons, ihre Morphologie und Stratigraphie mit Ausblicken auf Arten anderer Gebiete und Zeitabschnitte. Palaeontographica Abt. B, Band 98, pp. 136, Stuttgart 1955.

POWELL DUFFRYN TECHNICAL SERVICES LTD., Report on the Economics of Coal Production in the Livingstonia Coalfield, Nyasaland. London 1951.

RAISTRICK, A.: The Correlation of Coal Seams by Microspore Content, pt. 1 - The Seams of Northumberland. Trans.Inst.Min.Eng. Vol. lxxxviii, p. 142, 1934-35.

RAISTRICK, A.: The Correlation of Coal Seams by Microspore Content. Part 2. The Trencherbane Seam, Lancs., and the Busty Seam, Durham. Trans.Inst.Min.Eng. Vol. xcvii, p. 425, 1939.

RAISTRICK, A.: The Microscopic Analysis of Coal. Naturalist, July 1935.

RAISTRICK, A.: The microspores of coal and their use in correlation. CR. 11e Congr.Strat.Carb.Heerlen, ii, p. 909, 1935.

RAISTRICK, A. and J. SIMPSON: The microspores of some Northumberland coals and their use in the correlation of coal seams. Trans.Inst.Min.Eng., Vol. lxxxv, p. 225, 1932-33.

RILLETT, M.H.P.: (General Survey of Classification of spores in dissertation presented to the University of Cambridge for degree of M.Sc., 1952.)

RILLETT, M.H.P.: Plant Microfossils from the Coal Seams near Dannhauser, Natal. Trans.Geol.Soc.S.Africa, June 1954.

SCHOPF, J.M.: Spores from the Herrin (No 6) Coal bed in Illinois State. Geol.Survey Rep. of Investigation, No 50, Urbana, 1938.

SCHOPF, J.M., L.R. WILSON and RAY BENTALL: An annotated synopsis of Palaeozoic fossil spores and the definition of generic groups. Illinois, State.Geol.Survey, Reports of Investigation No 91, Urbana, Illinois 1944.

SEN, J. : Preliminary report on the microfloral correlation of the Satpulcuria, Ghusick and associated seams. Science & Culture, 10, pp. 58-59, 1944.

SEN, J. : Microfossils and the nature of coal in some Indian Coal Seams. Proc. 36th Indian Sci. Congress Abstracts, p. 113, 1949.

SEN, J. : Principles and problems of correlation of Indian Coal Seams with special reference to the Karharbari Coalfield. Bull.Nat.Inst.Sci.Ind., 2, pp. 129-139, 1953.

SEWARD, A.C.: Antarctic fossil plants (including diagnosis of Pityosporites) British Antarctic (Terra Nova) Expedition 1910. Natural History Report - Geology, Vol.1, No 1, pp.1-49, 1914.

SEWARD, A.C. An Antarctic Pollen grain - fact or fancy? New Phytologist, 1932.

SHERLOCK, R.L.: The Permo-Triassic Formations. Hutchinson's Scientific and Technical Publications, London 1947.

STOCKLEY, G.M.: Report on the Geology of the Ruhuhu Coal-fields; Njombe-Songea Districts. Bulletin No 2, Tanganyika Geological Survey Department, 1931.

STOCKLEY, G.M.: Geology of the Ruhuhu Coalfields Tanganyika Territory, with a report of some of the fossil plants from the Karoo rocks in the Ruhuhu River Depression (by J. WALTON). Q.J.G.S. Vol.88, pt. 4, p. 610, 1932.

STOCKLEY, G.M.: Further Contributions to the Geology of the Karoo of Tanganyika. Q.J.G.S. pt. 1, 1936.

THOMAS, H.H.: On some Pteridospermous plants from the Mesozoic Rocks of South Africa. Trans.Roy.Soc., Ser. B, 222, pp. 193-265, 1933.

VIRKKI, C.: On the Occurrence of winged spores in the Lower Gondwana Rocks of India and Australia. Proc.Ind.Acad.Sciences, Vol. VI, No 6, pp.428-430, Dec. 1937.

VIRKKI, C.: On the Occurrence of similar spores in a Lower Gondwana Glacial Tillite from Australia, and in Lower Gondwana Shales in India. Proc.Ind.Acad.Sciences, Vol. IX, No 1, Sec. B, pp. 7-10, 1939.

VIRKKI, C.: Spores from the Lower Gondwanas of India and Australia. Proc.Nat.Acad.Sciences India, Vol. 15, pts. 4-5, pp. 93-175, 1945.

WALTON, J.: The fossil flora of the Karoo System in the Wankie District of Southern Rhodesia. Bulletin No 15, Geol. Survey, S. Rhodesia, p. 62.

WILSON, L.R.: Spores and Pollen as Microfossils, Botanical Rev., 10, pp. 497-523, 1944.

WILSON, L.R.: Correlation of Sedimentary Rocks by fossil Spores and Pollen. Sed.Pet. 16, No 3, pp. 110-120, 1946.

WILSON, L.R. and E.A. COE: Descriptions of some unassigned plant microfossils from the Desmoines Series of Iowa. Am.Mid.Nat., 23, pp. 182-186, 1940.

ZETSCHE, F. and O. KALIN: Untersuchungen uber die Membran der Sporen und Pollen. Helv.Chim.Acta, XV, p. 412, 1932.

PLATE 1

SPORE 8a –

Showing striate ornamentation ? vestiges of wings

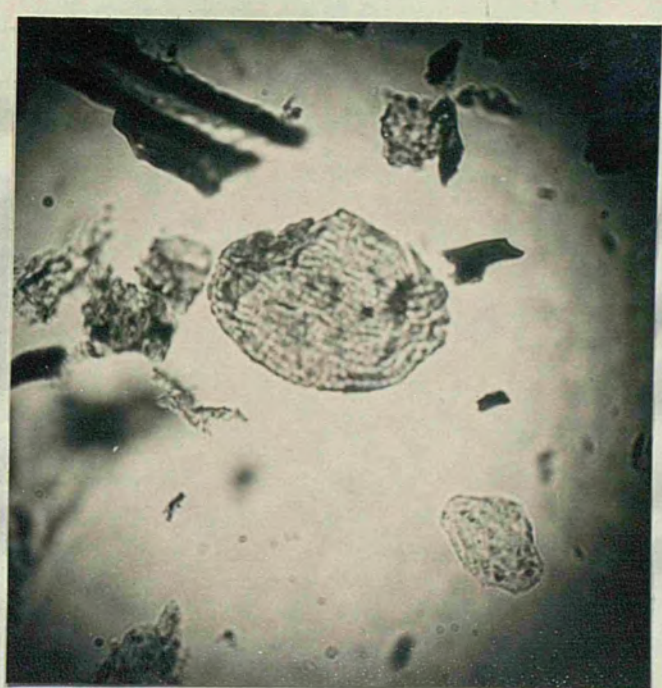
× 400

PLATE 2

SPORE 8a –

(Normal form) showing typical striate ornament.

× 400



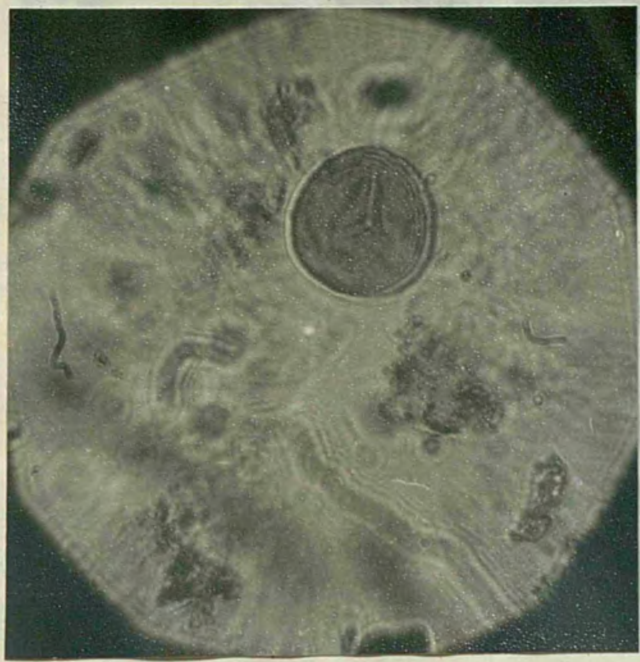


PLATE 3 × 600

SPORE 14a – showing trilete suture and lack of ornamentation

PLATE 4 × 400

SPORE 14b ~ Trilete suture shown extending across whole surface.

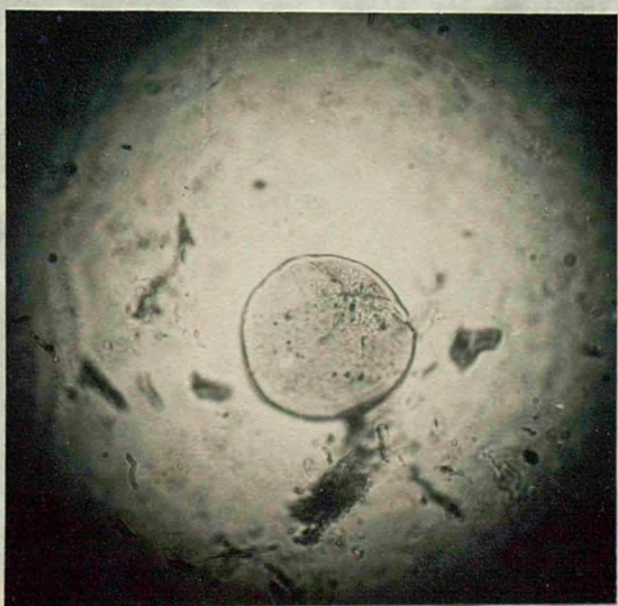


PLATE 5

SPORE 14c – slightly roughened surface to spore, small trilete suture.

× 400

PLATE 6

SPORE 12a ~ showing micro-reticulate ornament and trilete suture

x 600

PLATE 7

SPORE 18b. ~ verrucate ornament
No suture visible

x 600

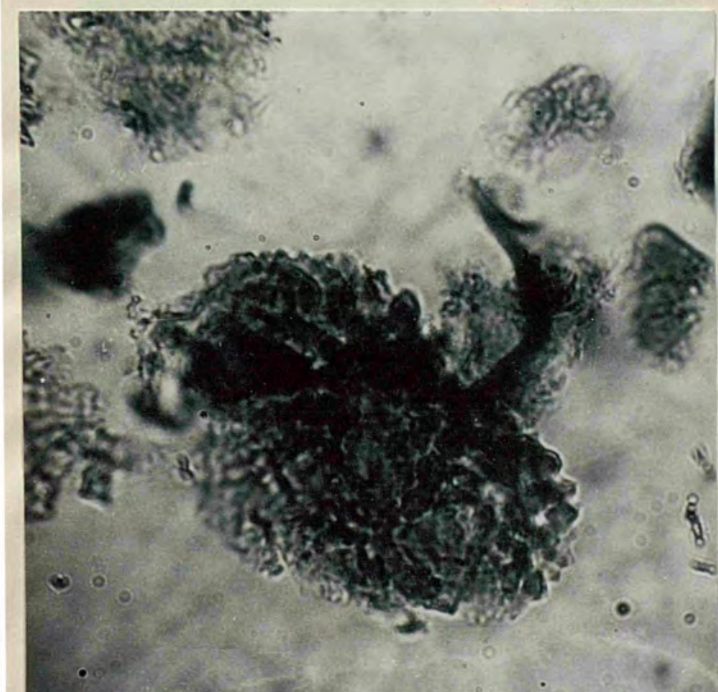
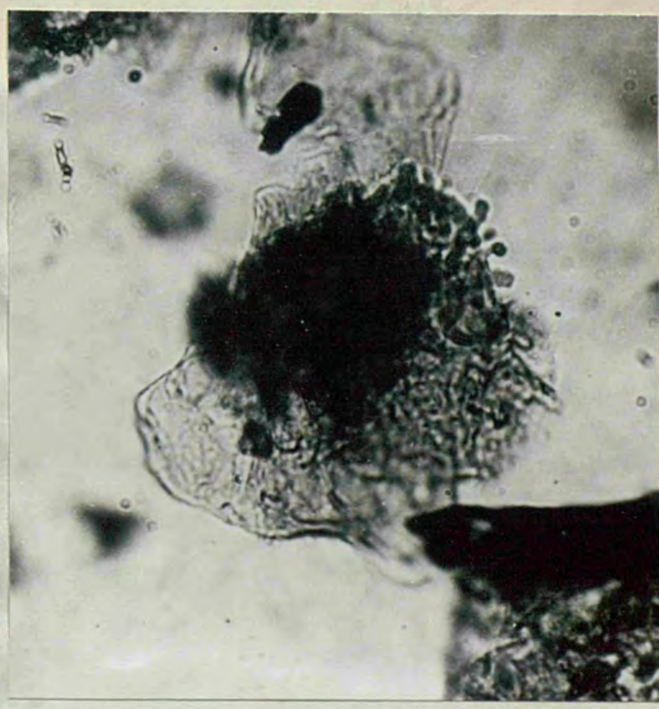


PLATE 8

SPORE 21c. ~ tuberculate ornament shown in silhouette

x 600



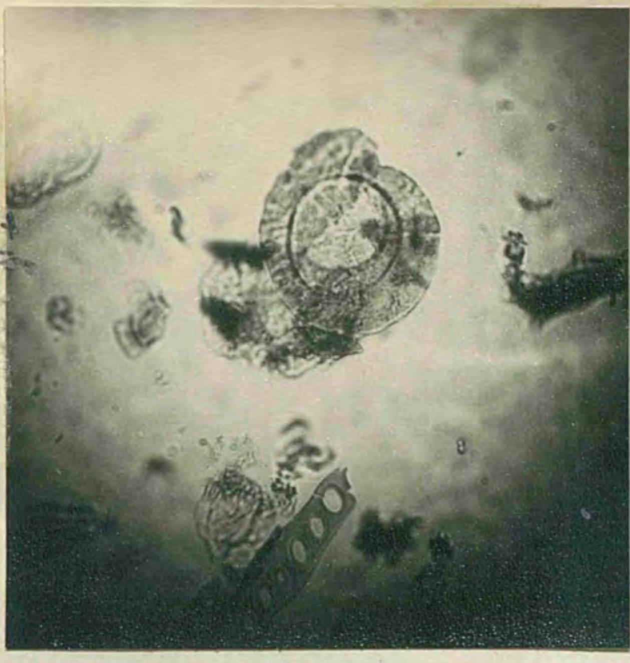


PLATE 9 ×300

SPORE 32a – Monowinged spore; showing distinct trilete suture. Broad wing, microreticulate ornament. [fragment of woody tissue at edge]

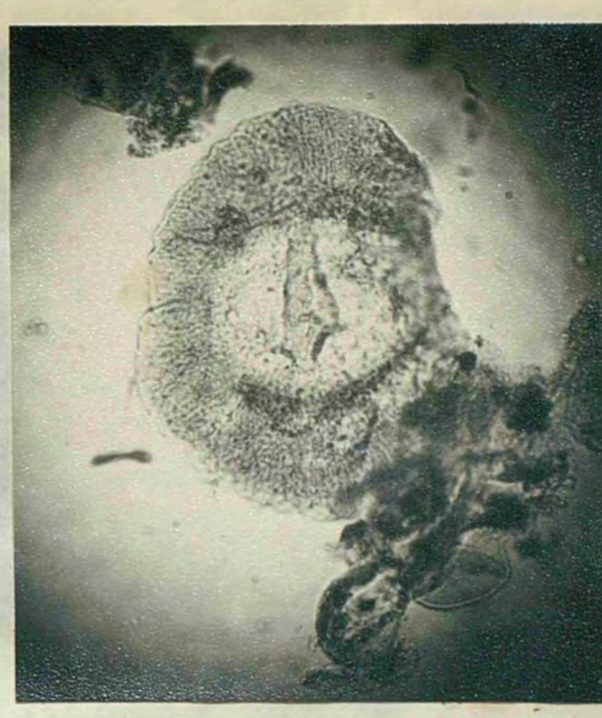


PLATE 10 × 400

SPORE 32c – Monowinged spore. Suture indistinct trilete – 2 long, one short arm. Wing broad at top and bottom, narrow at left and right overlap slight.

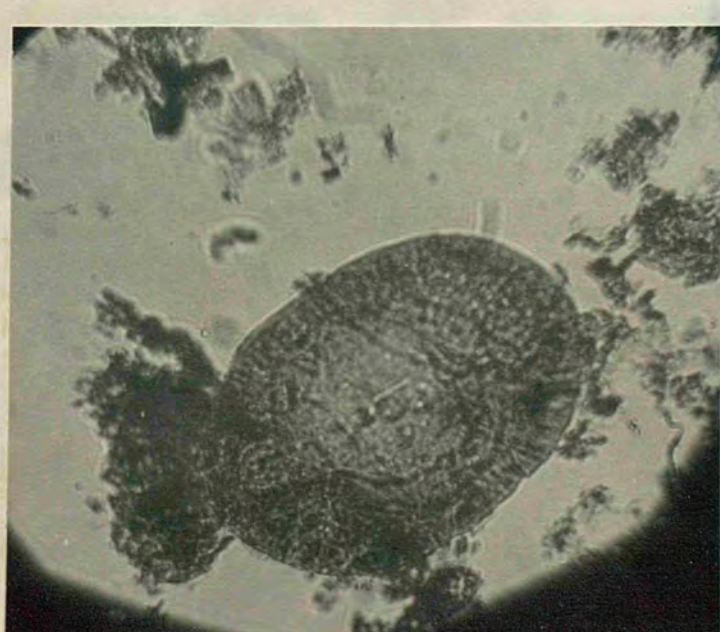
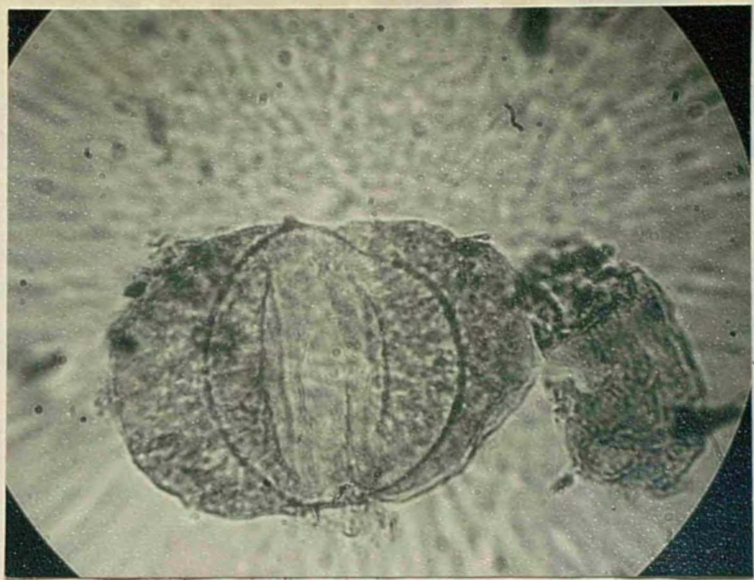


PLATE 11

SPORE 32c – Monowinged spore similar to Pl. 10. Suture not visible as trilete mark. Wing overlap considerable. Broad to left and right; narrow parts top left and bottom right.

× 400



12.   41b

PLATE 12

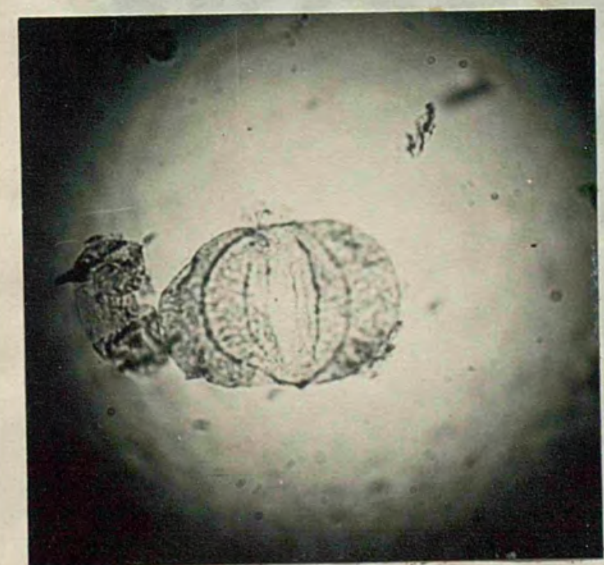
SPORE 41b – Spore with two air sacs, slightly larger than spore itself. Sacs attached at different position on each side, giving vertical stripes. No suture visible

× 600

PLATE 13

SPORE 41b – Spore with 2 air sacs, similar to Pl. 12. More contrast in plate shows wing attachments more clearly.

×400

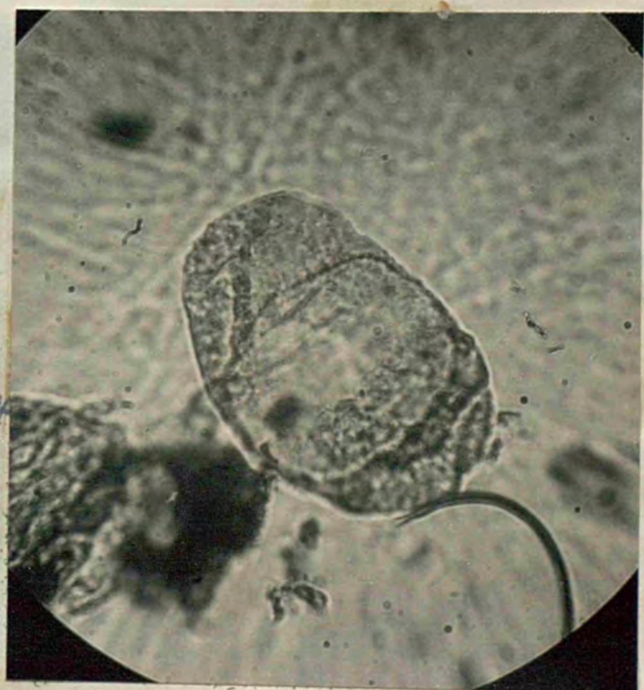


13.   41c.

PLATE 14

SPORE 41a – Spore with 2 air sacs which are smaller than spore body No suture visible

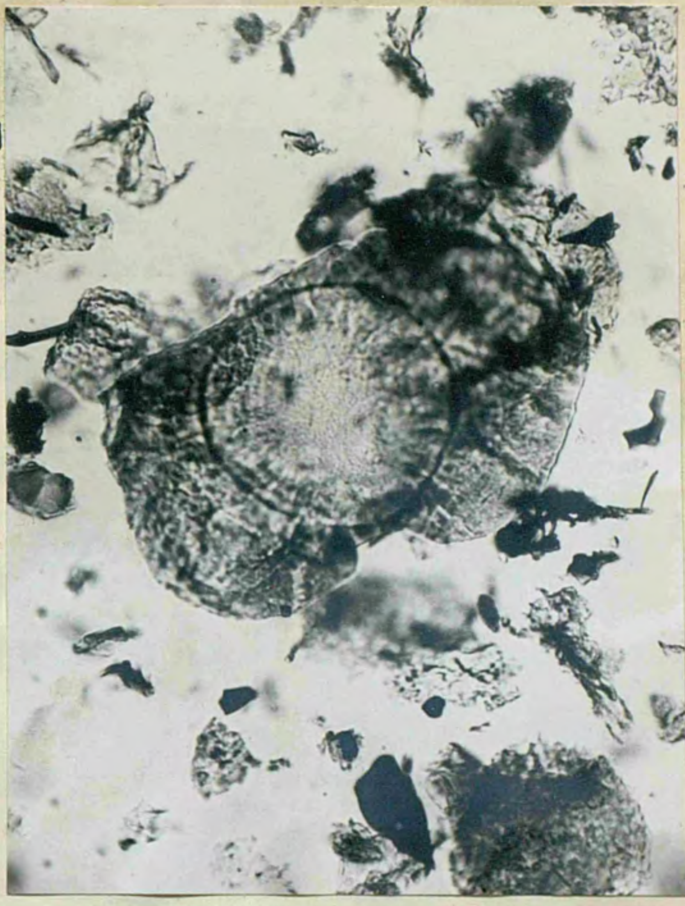
× 600



14.   41a

PLATE 15

SPORE 41c - showing large air sacs, which in this case, could be 'derived' from oval winged form - 32c



x 600

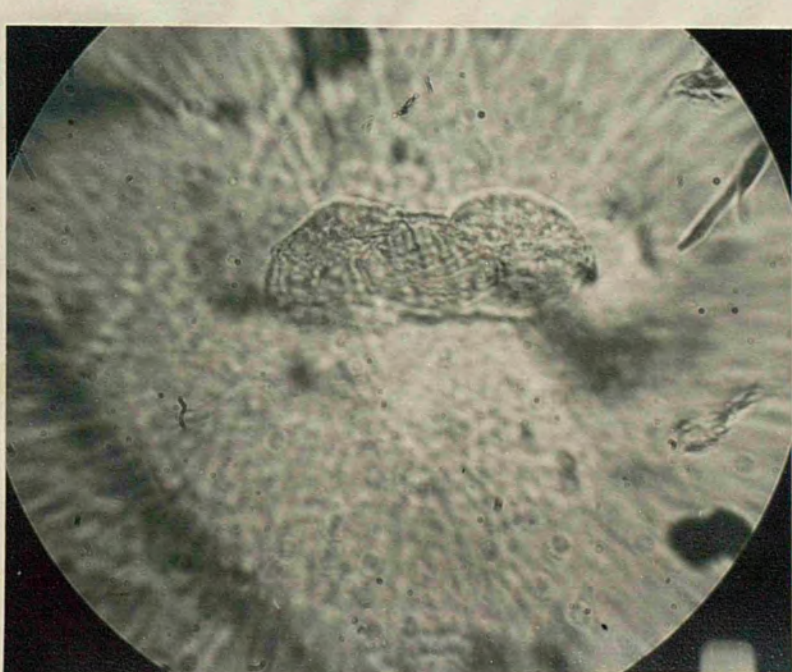


PLATE 16

SPORE 42b

Small bi-winged spore with large lateral air sacs, and transverse striations.

? Pityosporites sp.